Power System Analysis

B EE478: Simulation Project #1

by

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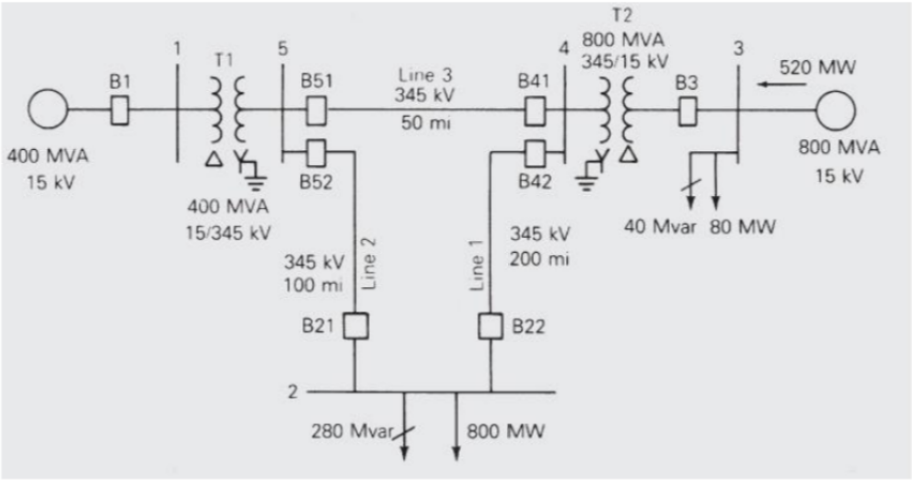
Lab Due Date: 11/14/2023

1. The single-line diagram of a five-bus power system is shown below. Machine, line, and transformer data are given in the following tables. This system is initially unloaded. Prefault voltages at all buses are 1.05 per unit.

Figure 1 - Power System Circuit Schematic



Single line diagram for the five-bus power system

TABLE 7.3

Synchronous machine data for SYMMETRICAL SHORT CIRCUITS program*

Bus	Machine Subtransient Reactance—X''_d (per unit)
1	0.045
3	0.0225

*S_{base} = 100 MVA
V_{base} = 15 kV at buses 1, 3
= 345 kV at buses 2, 4, 5

For Positive Sequence

New per unit (P.U.)

TABLE 7.4

Line data for SYMMETRICAL SHORT CIRCUITS program

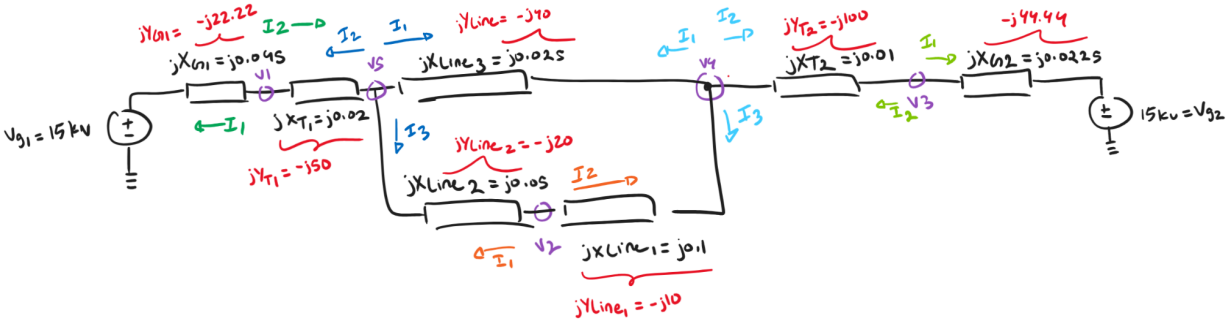
Bus-to-Bus	Equivalent Positive-Sequence Series Reactance (per unit)
2–4	0.1
2–5	0.05
4–5	0.025

TABLE 7.5

Transformer data for SYMMETRICAL SHORT CIRCUITS program

Bus-to-Bus	Leakage Reactance—X (per unit)
1–5	0.02
3–4	0.01

A) Hand calculate the bus admittance matrix *Ybus*. Clearly show how different elements of the bus admittance matrix are calculated. (5 Points)



@ V1

$I_1 = [V_1 - V_{s1}](-j22.22)$

$I_2 = [V_1 - V_5](-j50)$

$0 = I_1 + I_2$

$0 = V_1[-j22.22 + (-j50)] + V_5[j50] - V_{g1}[(-j22.22)]$

$0 = V_1[-j72.22] + V_5[j50] - V_{g1}[(-j22.22)]$

@ V5

$I_1 = [V_5 - V_4](-j40)$

$I_2 = [V_5 - V_1](-j50)$

$I_3 = [V_5 - V_2](-j20)$

$0 = I_1 + I_2 + I_3$

$0 = -V_1[(-j50)] - V_2[(-j20)] - V_4[(-j40)] + V_5[(-j40) + (-j50) + (-j20)]$

$0 = -V_1[(-j50)] - V_2[(-j20)] - V_4[(-j40)] + V_5[(-j110)]$

@ V2

$I_1 = [V_2 - V_3](-j20)$

$I_2 = [V_2 - V_4](-j10)$

$0 = I_1 + I_2$

$0 = V_2[(-j20) + (-j10)] - V_4[(-j10)] - V_5[(-j20)]$

$0 = V_2[(-j30)] - V_4[(-j10)] - V_5[(-j20)]$

@V4

$I_1 = [V_4 - V_5](-j40)$

$I_2 = [V_4 - V_3](-j100)$

$I_3 = [V_4 - V_2](-j10)$

$0 = I_1 + I_2 + I_3$

$0 = -V_2[(-j10)] - V_3[(-j100)] + V_4[(-j40) + (-j10) + (-j100)] - V_5[(-j40)]$

$0 = -V_2[(-j10)] - V_3[(-j100)] + V_4[(-j150)] - V_5[(-j40)]$

@V3

$I_1 = [V_3 - V_{32}](-j44.44)$

$I_2 = [V_3 - V_4](-j100)$

$0 = I_1 + I_2$

$0 = V_3[(-j44.44) + (-j100)] - V_4[(-j100)] - V_{32}(-j100)$

$0 = V_3[(-j144.44)] - V_4(-j100) - V_{32}(-j100)$

$$\begin{bmatrix} -j72.22 & 0 & 0 & 0 & j50 \\ 0 & -j30 & 0 & j10 & j20 \\ 0 & 0 & -j144.44 & j100 & 0 \\ 0 & j10 & j100 & -j150 & j40 \\ j50 & j20 & 0 & j40 & -j110 \end{bmatrix} = Y_{bus}$$

B) Use the *Ybus* to calculate the bus impedance matrix (*Zbus*). (5 Points)

$$Y_{bus}^{-1} = Z_{bus}$$

$$\begin{bmatrix} -j72.22 & 0 & 0 & 0 & j50 \\ 0 & -j30 & 0 & j10 & j20 \\ 0 & 0 & -j144.44 & j100 & 0 \\ 0 & j10 & j100 & -j150 & j40 \\ j50 & j20 & 0 & j40 & -j110 \end{bmatrix}^{-1} = j \begin{bmatrix} 0.0279 & 0.0177 & 0.0085 & 0.0129 & 0.0204 \\ 0.0177 & 0.05695 & 0.0136 & 0.0197 & 0.0255 \\ 0.0085 & 0.0136 & 0.0182 & 0.0163 & 0.0122 \\ 0.01229 & 0.0197 & 0.0163 & 0.0236 & 0.0177 \\ 0.0204 & 0.0255 & 0.0122 & 0.01774 & 0.0294 \end{bmatrix} = Z_{bus}$$

Y_{bus}^{-1} → Z_{bus}

C) Use the appropriate elements of the *Zbus* to calculate the fault current for three-phase faults at each of the buses. (10 Points)

@ I_{Fault} @ V_1

$$I_{Fault} = \frac{V_{prefault}}{Z_{th\,@\,V_1}} = \frac{1.05}{j0.0279} = -j37.63 \text{ p.u.}$$

@ I_{Fault} @ V_2

$$I_{Fault} = \frac{V_{prefault}}{Z_{th\,@\,V_2}} = \frac{1.05}{j0.05695} = -j18.43 \text{ p.u.}$$

@ I_{Fault} @ V_3

$$I_{Fault} = \frac{V_{prefault}}{Z_{th\,@\,V_3}} = \frac{1.05}{j0.0182} = -j57.69 \text{ p.u.}$$

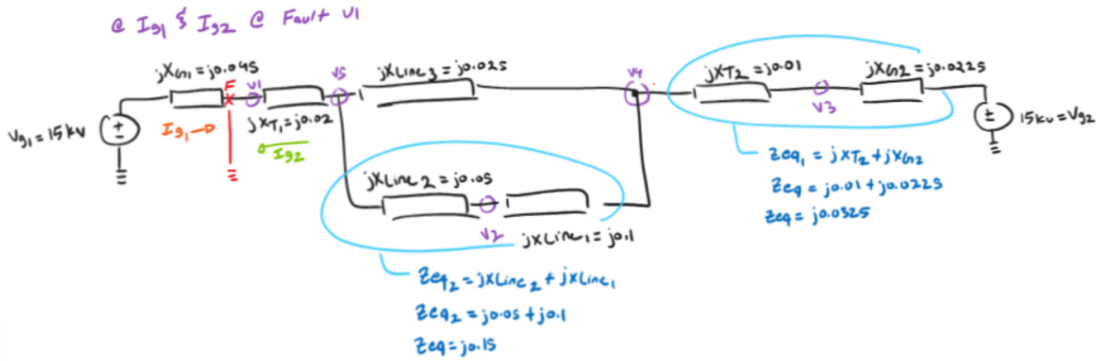
@ I_{Fault} @ V_4

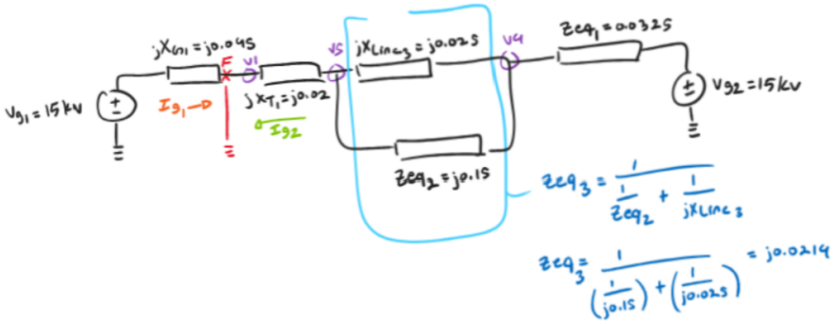
$$I_{Fault} = \frac{V_{prefault}}{Z_{th\,@\,V_4}} = \frac{1.05}{j0.0236} = -j44.49 \text{ p.u.}$$

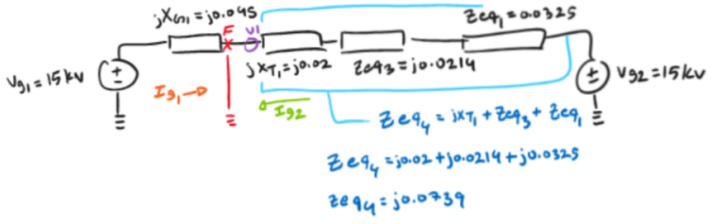
@ I_{Fault} @ V_5

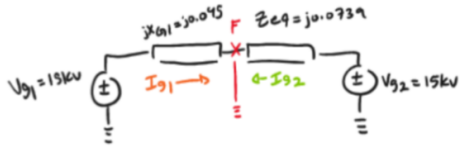
$$I_{Fault} = \frac{V_{prefault}}{Z_{th\,@\,V_5}} = \frac{1.05}{j0.0294} = -j35.71 \text{ p.u.}$$

D) Use the current-division rule to calculate the generators' contributions to the fault current ($IG1$ (F),$IG2$ (F)) for each fault (Convert the Δ-connected lines to its equivalent Y, if necessary). (20 Points)









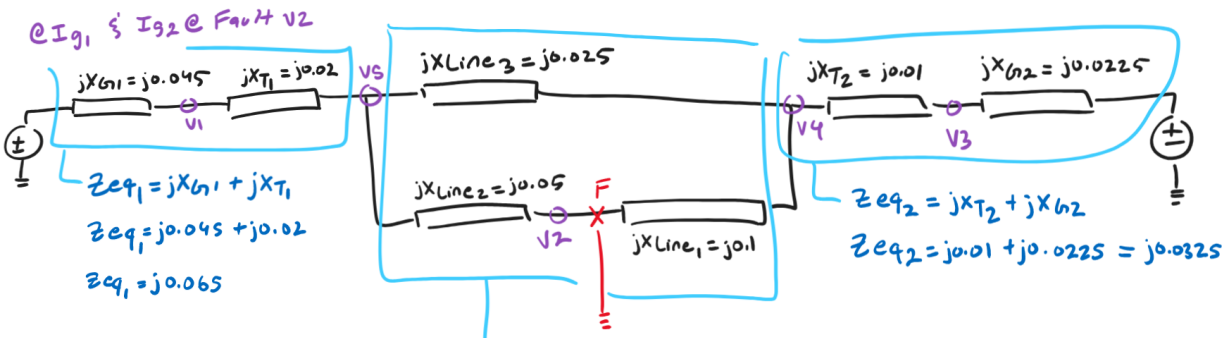
$I_X = \left(\frac{B_T}{B_{Tx} + B_T}\right) I_T$ & Current divider

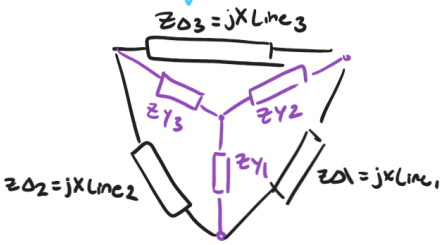
@ I_{g1}

$I_{g1} = \left[\frac{Zeq}{jX_{G1} + Zeq}\right] I_F = \left[\frac{j0.0739}{j0.045 + j0.0739}\right](-j37.63) = -j23.57$ P.U.

@ I_{g2}

$I_{g2} = \left[\frac{jX_{G1}}{Zeq + jX_{G1}}\right](I_F) = \left[\frac{j0.045}{j0.0739 + j0.045}\right](-j37.63) = -j14.24$ P.U.





$$Z_{Y1} = \frac{Z_{\Delta1} \cdot Z_{\Delta2}}{Z_{\Delta1} + Z_{\Delta2} + Z_{\Delta3}}$$

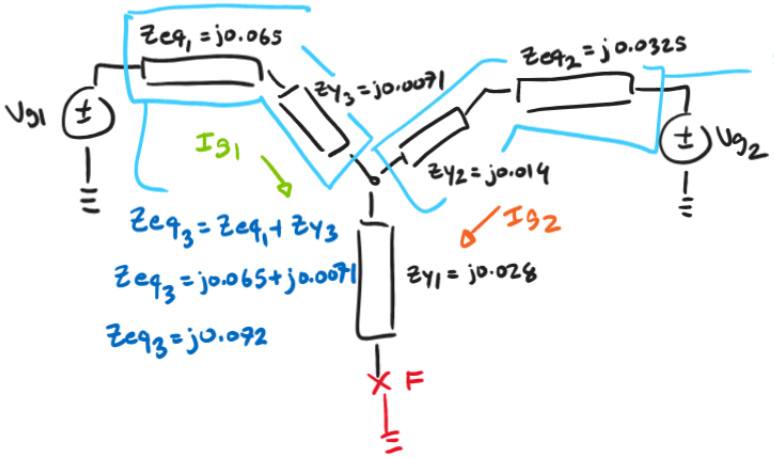
$$Z_{Y2} = \frac{Z_{\Delta1} \cdot Z_{\Delta3}}{Z_{\Delta1} + Z_{\Delta2} + Z_{\Delta3}}$$

$$Z_{Y3} = \frac{Z_{\Delta2} \cdot Z_{\Delta3}}{Z_{\Delta1} + Z_{\Delta2} + Z_{\Delta3}}$$

$$Z_{Y1} = \frac{jX_{Line1} \cdot jX_{Line2}}{jX_{Line1} + jX_{Line2} + jX_{Line3}} = \frac{j0.1 \cdot j0.05}{j0.1 + j0.05 + j0.025} = j0.028$$

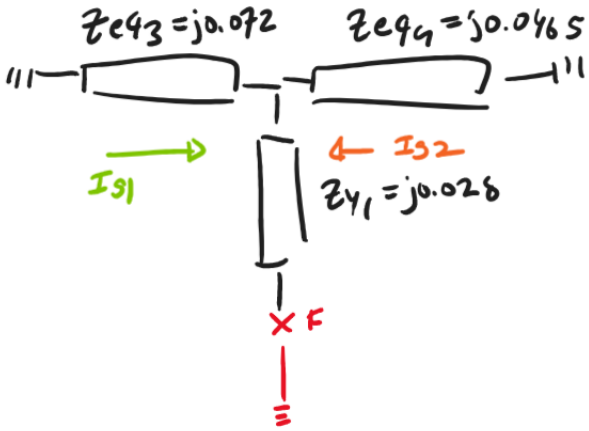
$$Z_{Y2} = \frac{jX_{Line1} + jX_{Line3}}{jX_{Line1} + jX_{Line2} + jX_{Line3}} = \frac{j0.01 + j0.025}{j0.1 + j0.05 + j0.025} = j0.014$$

$$Z_{Y3} = \frac{jX_{Line2} + jX_{Line3}}{jX_{Line1} + jX_{Line2} + jX_{Line3}} = \frac{j0.05 + j0.025}{j0.1 + j0.05 + j0.025} = j0.0071$$



$$Z_{eq4} = Z_{Y2} + Z_{eq2}$$

$$Z_{eq4} = j0.014 + j0.0325 = j0.0465$$



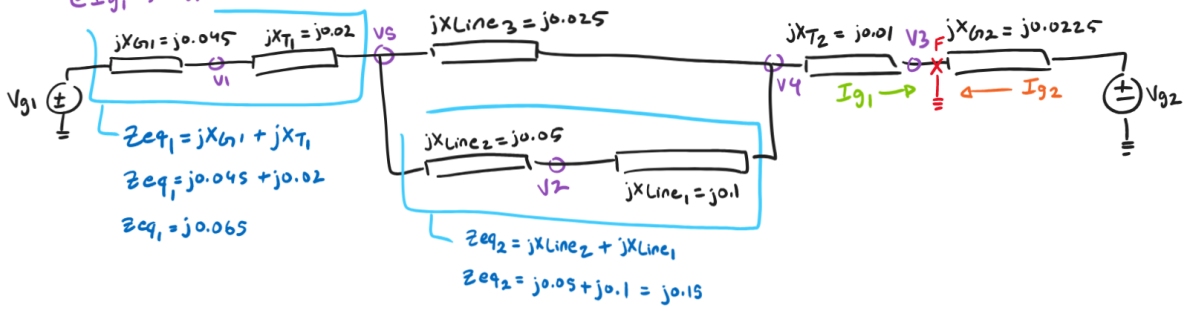
@I_{g1}

$$I_{g1} = \left[\frac{Z_{eq_4}}{Z_{eq_3} + Z_{eq_4}}\right](I_F) = \frac{j0.0465}{j0.072 + j0.0465}(-j18.43) = -j4.23 \text{ P.U.}$$

@I_{g2}

$$I_{g2} = \left[\frac{Z_{eq_3}}{Z_{eq_3} + Z_{eq_4}}\right](I_F) = \frac{j0.072}{j0.072 + j0.0465}(-j18.43) = -j11.19 \text{ P.U.}$$

@ I_{g1} & I_{g2} @ Fault V_3



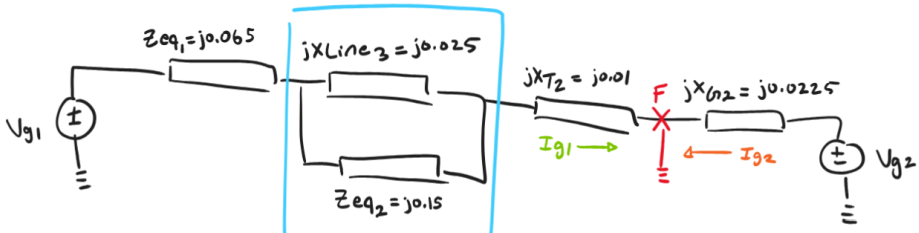
$Zeq_1 = jX_{G1} + jX_{T1}$

$Zeq_1 = j0.045 + j0.02$

$Zeq_1 = j0.065$

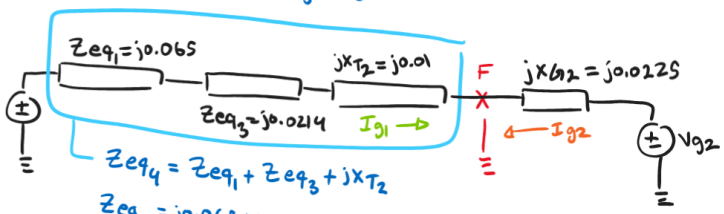
$Zeq_2 = jX_{Line2} + jX_{Line1}$

$Zeq_2 = j0.05 + j0.1 = j0.15$



$$Zeq_3 = \frac{1}{\frac{1}{Zeq_2} + \frac{1}{jX_{Line3}}}$$

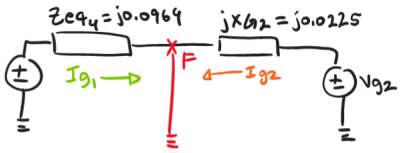
$$Zeq_3 = \frac{1}{\frac{1}{j0.15} + \frac{1}{j0.025}} = j0.0214$$



$Zeq_4 = Zeq_1 + Zeq_3 + jX_{T2}$

$Zeq_4 = j0.065 + j0.0214 + j0.01$

$Zeq_4 = j0.0964$

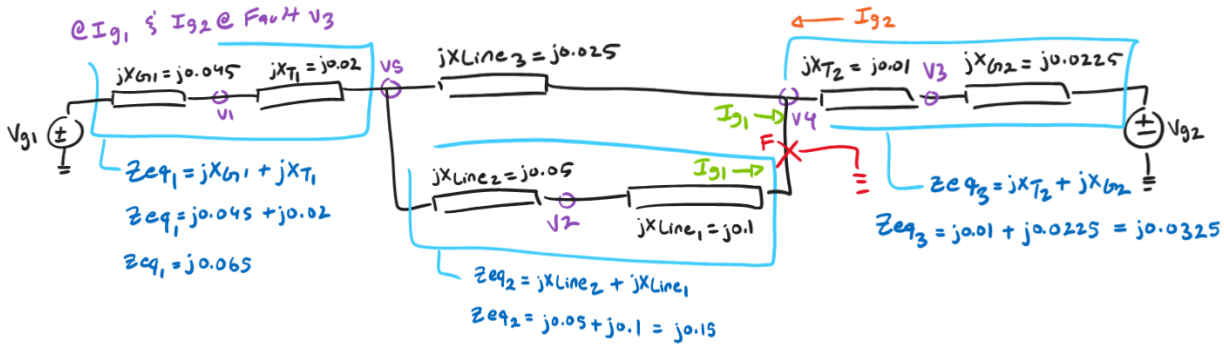


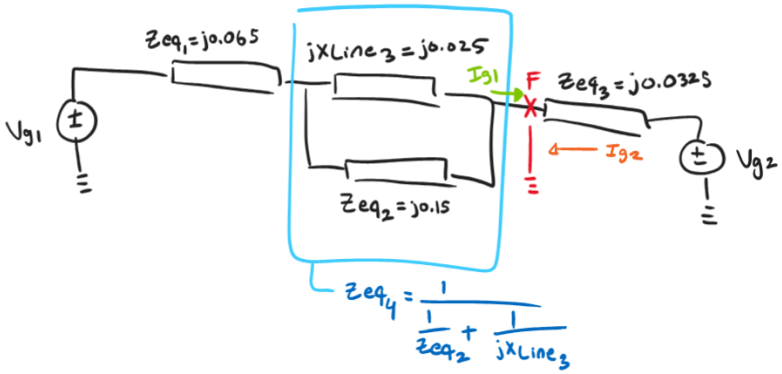
@ I_{g1}

$$I_{g1} = \left[\frac{Zeq_4}{Zeq_4 + jX_{G2}}\right](I_F) = \left[\frac{j0.0964}{(j0.0964)+(j0.0225)}\right](-j57.69) = -j46.77 \text{ p.u.}$$

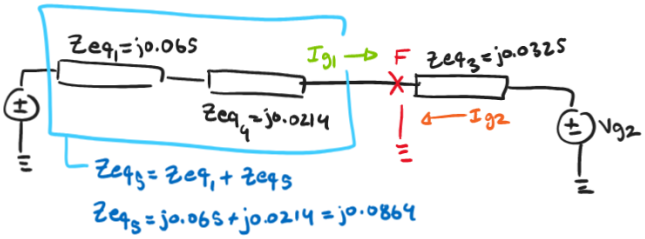
@ I_{g2}

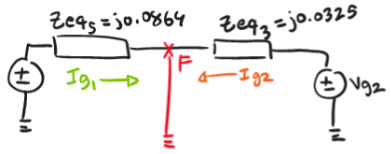
$$I_{g2} = \left[\frac{jX_{G2}}{Zeq_4 + jX_{G2}}\right](I_F) = \left[\frac{(j0.0225)}{(j0.0964)+(j0.0225)}\right](-j57.69) = -j10.91 \text{ p.u.}$$





$$Zeq_4 = \frac{1}{\frac{1}{j0.15} + \frac{1}{j0.025}} = j0.0214$$



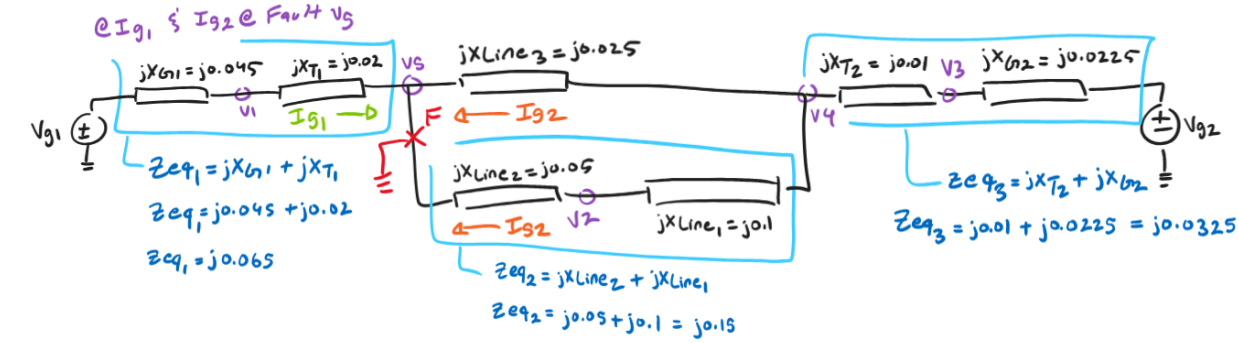


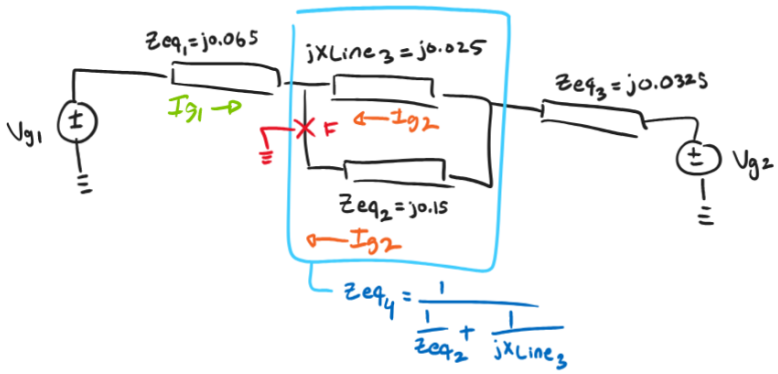
@ I_{g1}

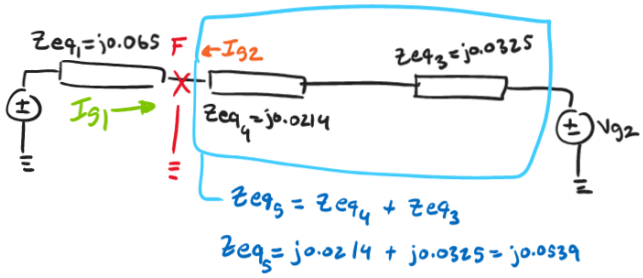
$$I_{g1} = \left[\frac{Zeq_5}{Zeq_5 + Zeq_3}\right](I_F) = \left[\frac{(j0.0864)}{(j0.0864)+(j0.0325)}\right](-j44.44) = -j32.33 \text{ P.U.}$$

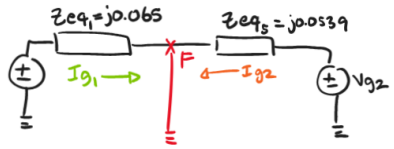
@ I_{g2}

$$I_{g2} = \left[\frac{Zeq_3}{Zeq_5 + Zeq_3}\right](I_F) = \left[\frac{(j0.0325)}{(j0.0864)+(j0.0325)}\right](-j44.44) = -j12.16 \text{ P.U.}$$









@ I_{g1}

$$I_{g1} = \left[\frac{Zeq_5}{Zeq_5 + Zeq_1}\right](I_F) = \left[\frac{(j0.0539)}{(j0.0539)+(j0.065)}\right](-j35.71) = -j16.18 \text{ p.u.}$$

@ I_{g2}

$$I_{g2} = \left[\frac{Zeq_1}{Zeq_5 + Zeq_1}\right](I_F) = \left[\frac{(j0.065)}{(j0.0539)+(j0.065)}\right](-j35.71) = -j19.52 \text{ p.u.}$$

E) Use the $Zbus$ and the vector of bus injected currents to calculate the per-unit bus voltages during each fault ($V1$ (F),$V2$ (F),$V3$ (F),$V4$ (F), $V5$ (F)). (20 Points)

@ V_{Fault} @ V_1

$$j\begin{bmatrix} 0.0279 & 0.0177 & 0.0085 & 0.0129 & 0.0204 \\ 0.0177 & 0.05695 & 0.0136 & 0.0197 & 0.0255 \\ 0.0085 & 0.0136 & 0.0182 & 0.0163 & 0.0122 \\ 0.01229 & 0.0197 & 0.0163 & 0.0236 & 0.0177 \\ 0.0204 & 0.0255 & 0.0122 & 0.01774 & 0.0294 \end{bmatrix} \cdot \begin{bmatrix} -(-j37.63) \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} V_1^{(2)} = -1.05 \\ V_2^{(2)} = -0.66 \\ V_3^{(2)} = -0.32 \\ V_4^{(2)} = -0.46 \\ V_5^{(2)} = -0.76 \end{bmatrix} P.U.$$

- $-(-j37.63)$: $-I_F$ here due to Fault location
- Z bus
- I bus
- Voltage @ System #2

$$\begin{bmatrix} V_1^{(1)} = 1.05 \\ V_2^{(1)} = 1.05 \\ V_3^{(1)} = 1.05 \\ V_4^{(1)} = 1.05 \\ V_5^{(1)} = 1.05 \end{bmatrix} + \begin{bmatrix} V_1^{(2)} = -1.05 \\ V_2^{(2)} = -0.66 \\ V_3^{(2)} = -0.32 \\ V_4^{(2)} = -0.46 \\ V_5^{(2)} = -0.76 \end{bmatrix} = \begin{bmatrix} V_1^{(F)} = 0 \\ V_2^{(F)} = 0.39 \\ V_3^{(F)} = 0.73 \\ V_4^{(F)} = 0.59 \\ V_5^{(F)} = 0.29 \end{bmatrix} P.U.$$

- Prefault Voltage
- Voltage @ 2nd system
- Fault Voltage

@ V_{Fault} @ V_2

$$j\begin{bmatrix} 0.0279 & 0.0177 & 0.0085 & 0.0129 & 0.0204 \\ 0.0177 & 0.05695 & 0.0136 & 0.0197 & 0.0255 \\ 0.0085 & 0.0136 & 0.0182 & 0.0163 & 0.0122 \\ 0.01229 & 0.0197 & 0.0163 & 0.0236 & 0.0177 \\ 0.0204 & 0.0255 & 0.0122 & 0.01774 & 0.0294 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ -(-j18.43) \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} V_1^{(2)} = -0.326 \\ V_2^{(2)} = -1.049 \\ V_3^{(2)} = -0.251 \\ V_4^{(2)} = -0.363 \\ V_5^{(2)} = -0.471 \end{bmatrix} P.U.$$

- Z bus
- I bus
- Voltage @ System #2

$$\begin{bmatrix} V_1^{(1)} = 1.05 \\ V_2^{(1)} = 1.05 \\ V_3^{(1)} = 1.05 \\ V_4^{(1)} = 1.05 \\ V_5^{(1)} = 1.05 \end{bmatrix} + \begin{bmatrix} V_1^{(2)} = -0.326 \\ V_2^{(2)} = -1.049 \\ V_3^{(2)} = -0.251 \\ V_4^{(2)} = -0.363 \\ V_5^{(2)} = -0.471 \end{bmatrix} = \begin{bmatrix} V_1^{(F)} = 0.724 \\ V_2^{(F)} = 0.201 \\ V_3^{(F)} = 0.799 \\ V_4^{(F)} = 0.687 \\ V_5^{(F)} = 0.579 \end{bmatrix} P.U.$$

- Prefault voltage
- Voltage @ 2nd system
- Fault voltage

@ V_{Fault} @ V_3

$$j\begin{bmatrix} 0.0279 & 0.0177 & 0.0085 & 0.0129 & 0.0204 \\ 0.0177 & 0.05695 & 0.0136 & 0.0197 & 0.0255 \\ 0.0085 & 0.0136 & 0.0182 & 0.0163 & 0.0122 \\ 0.01229 & 0.0197 & 0.0163 & 0.0236 & 0.0177 \\ 0.0204 & 0.0255 & 0.0122 & 0.01774 & 0.0294 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 0 \\ -(-j57.69) \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} V_1^{(2)} = -0.49 \\ V_2^{(2)} = -0.78 \\ V_3^{(2)} = -1.05 \\ V_4^{(2)} = -0.94 \\ V_5^{(2)} = -0.71 \end{bmatrix} P.U.$$

Z bus | I bus | Voltage @ System #2

$$\begin{bmatrix} V_1^{(1)} = 1.05 \\ V_2^{(1)} = 1.05 \\ V_3^{(1)} = 1.05 \\ V_4^{(1)} = 1.05 \\ V_5^{(1)} = 1.05 \end{bmatrix} + \begin{bmatrix} V_1^{(2)} = -0.49 \\ V_2^{(2)} = -0.78 \\ V_3^{(2)} = -1.05 \\ V_4^{(2)} = -0.94 \\ V_5^{(2)} = -0.71 \end{bmatrix} = \begin{bmatrix} V_1^{(F)} = 0.55 \\ V_2^{(F)} = 0.26 \\ V_3^{(F)} = 0.00 \\ V_4^{(F)} = 0.10 \\ V_5^{(F)} = 0.34 \end{bmatrix} P.U.$$

Prefault Voltage | Voltage @ 2nd System | Fault Voltage

@ V_{Fault} @ V_4

$$j\begin{bmatrix} 0.0279 & 0.0177 & 0.0085 & 0.0129 & 0.0204 \\ 0.0177 & 0.05695 & 0.0136 & 0.0197 & 0.0255 \\ 0.0085 & 0.0136 & 0.0182 & 0.0163 & 0.0122 \\ 0.01229 & 0.0197 & 0.0163 & 0.0236 & 0.0177 \\ 0.0204 & 0.0255 & 0.0122 & 0.01774 & 0.0294 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 0 \\ 0 \\ -(-j44.49) \\ 0 \end{bmatrix} = \begin{bmatrix} V_1^{(2)} = -0.547 \\ V_2^{(2)} = -0.877 \\ V_3^{(2)} = -0.727 \\ V_4^{(2)} = -1.051 \\ V_5^{(2)} = -0.790 \end{bmatrix} P.U$$

Z bus | I bus | Voltage @ System #2

$$\begin{bmatrix} V_1^{(1)} = 1.05 \\ V_2^{(1)} = 1.05 \\ V_3^{(1)} = 1.05 \\ V_4^{(1)} = 1.05 \\ V_5^{(1)} = 1.05 \end{bmatrix} + \begin{bmatrix} V_1^{(2)} = -0.547 \\ V_2^{(2)} = -0.877 \\ V_3^{(2)} = -0.727 \\ V_4^{(2)} = -1.051 \\ V_5^{(2)} = -0.790 \end{bmatrix} = \begin{bmatrix} V_1^{(F)} = 0.503 \\ V_2^{(F)} = 0.173 \\ V_3^{(F)} = 0.323 \\ V_4^{(F)} = 0.00 \\ V_5^{(F)} = 0.26 \end{bmatrix} P.U.$$

Prefault Voltage | Voltage @ 2nd System | Fault Voltage

@ V_{Fault} @ Vs

$$j\begin{bmatrix} 0.0279 & 0.0177 & 0.0085 & 0.0129 & 0.0204 \\ 0.0177 & 0.05695 & 0.0136 & 0.0197 & 0.0255 \\ 0.0085 & 0.0136 & 0.0182 & 0.0163 & 0.0122 \\ 0.01229 & 0.0197 & 0.0163 & 0.0236 & 0.0177 \\ 0.0204 & 0.0255 & 0.0122 & 0.01774 & 0.0294 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ -(-j35.71) \end{bmatrix} = \begin{bmatrix} V_1^{(2)} = -0.92 \\ V_2^{(2)} = -0.91 \\ V_3^{(2)} = -0.43 \\ V_4^{(2)} = -0.63 \\ V_5^{(2)} = -1.049 \end{bmatrix}$$

Zbus

Ibus

Voltage @ system #2

$$\begin{bmatrix} V_1^{(1)} = 1.05 \\ V_2^{(1)} = 1.05 \\ V_3^{(1)} = 1.05 \\ V_4^{(1)} = 1.05 \\ V_5^{(1)} = 1.05 \end{bmatrix} + \begin{bmatrix} V_1^{(2)} = -0.92 \\ V_2^{(2)} = -0.91 \\ V_3^{(2)} = -0.43 \\ V_4^{(2)} = -0.63 \\ V_5^{(2)} = -1.049 \end{bmatrix} = \begin{bmatrix} V_1^{(F)} = 0.321 \\ V_2^{(F)} = 0.139 \\ V_3^{(F)} = 0.611 \\ V_4^{(F)} = 0.417 \\ V_5^{(F)} = 0.00 \end{bmatrix}$$

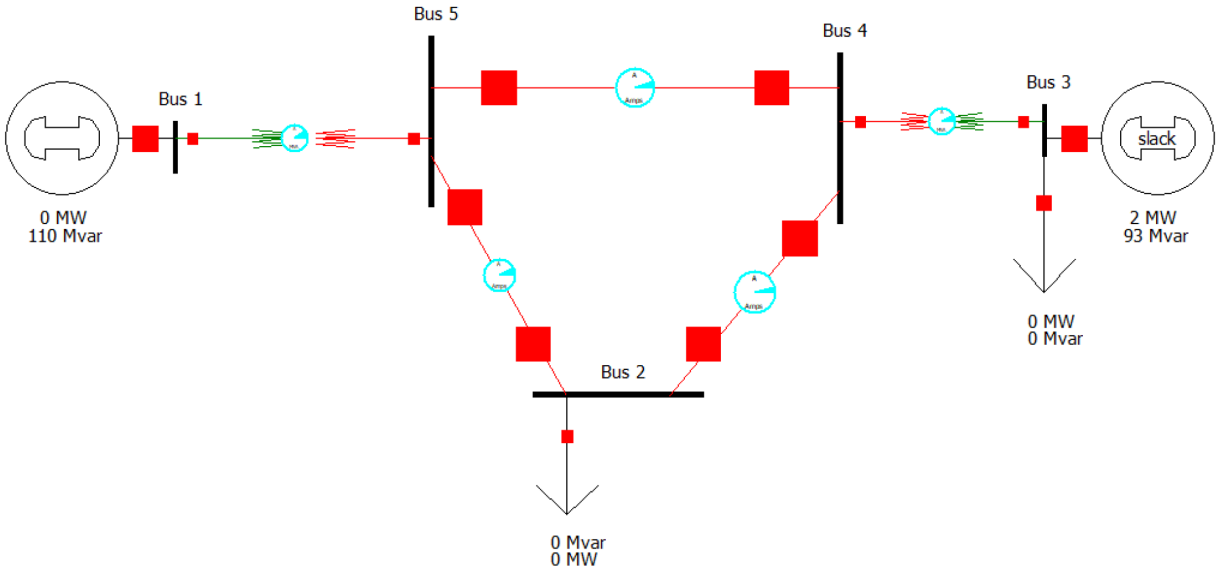
Prefault Voltage

Voltage @ 2nd System

Fault Voltage

F) Build the five-bus power system in PowerWorld Simulator. (10 Points)

Figure 2 - PowerWorld Circuit of Figure 1

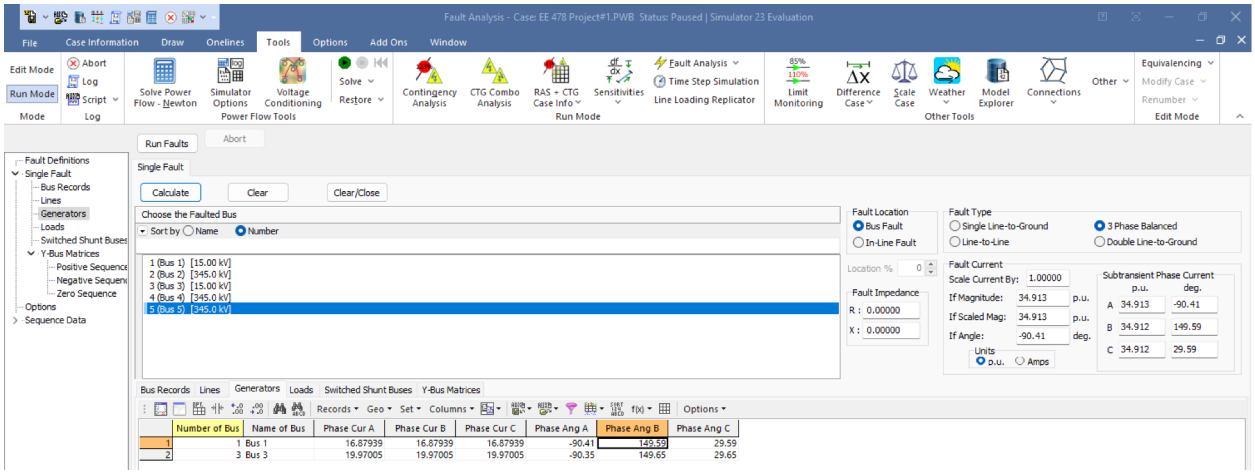


When working with the Powerworld simulation, the first thing that needs to be added are the buses, located by selecting *Draw > Network > Bus*. In the *Bus Option,* the Nominal Voltage is set to the Vbase provided by Figure 1, and the orientation seen in *Bus option > display*.

The Generator, Transmission Line, and Transformer can be located in *Draw > Network*. When adding the transmission Line and transformer, click on one of the buses and then double-right-click on a bus where you want to end. Then input your desired values which can be seen in the appendix for each component. One thing observed is that when the circuit is simulated the set parameters will change.

G) Use the power system that you built in PowerWorld Simulator for part (f) and confirm the results of parts c, d and e. Take screenshots of the dialog boxes and paste them here. (30 Points)

When the circuit, seen in Figure 2, has been constructed select run mode > Tool > the green arrow to simulate the circuit. Select Fault analysis, seen under tools, to find the results.



When a bus is selected and calculated the fault current can be located on the right side. After calculation, the generators' contributions to the fault current can be located under the Gerorators Tab. The per-unit bus voltages during each fault can be located under the Bus Records Tab.

G.C) The fault current for three-phase faults at each of the buses

Figure 3 - PowerWorld fault current for three-phase faults at bus 1

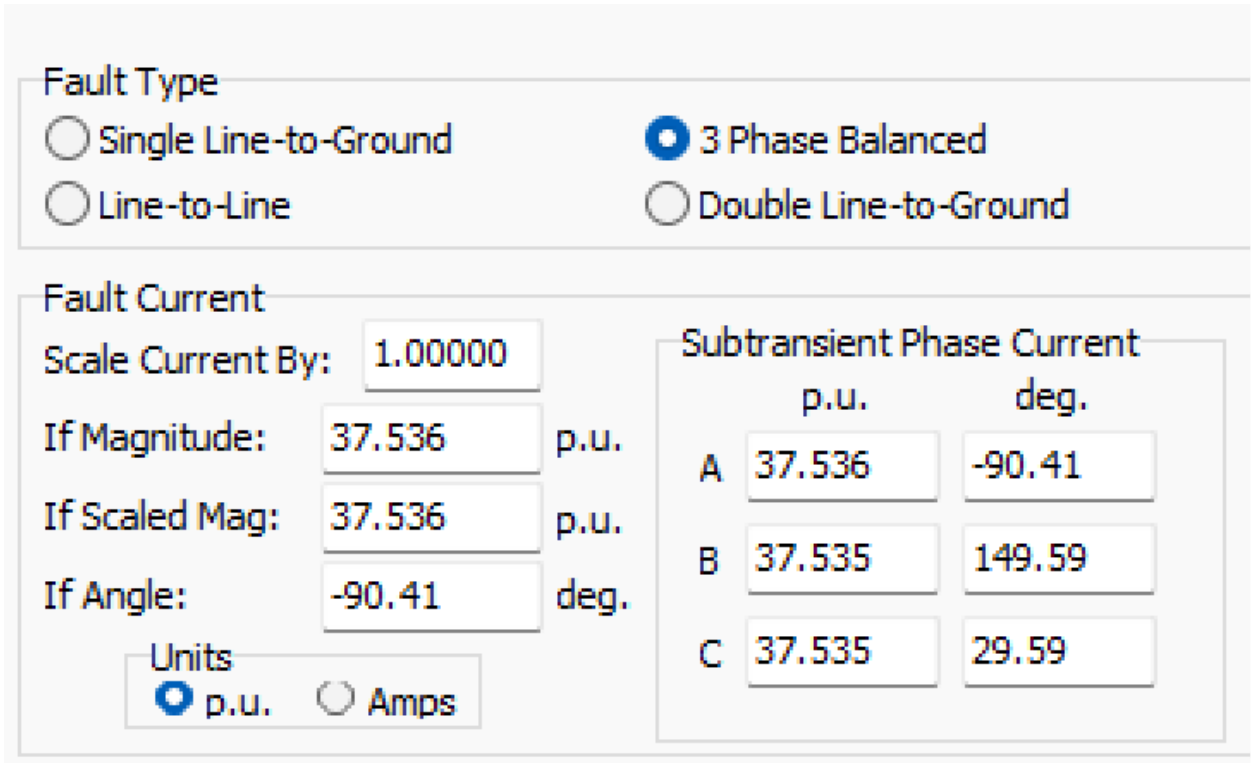


Figure 4 - PowerWorld fault current for three-phase faults at bus 2

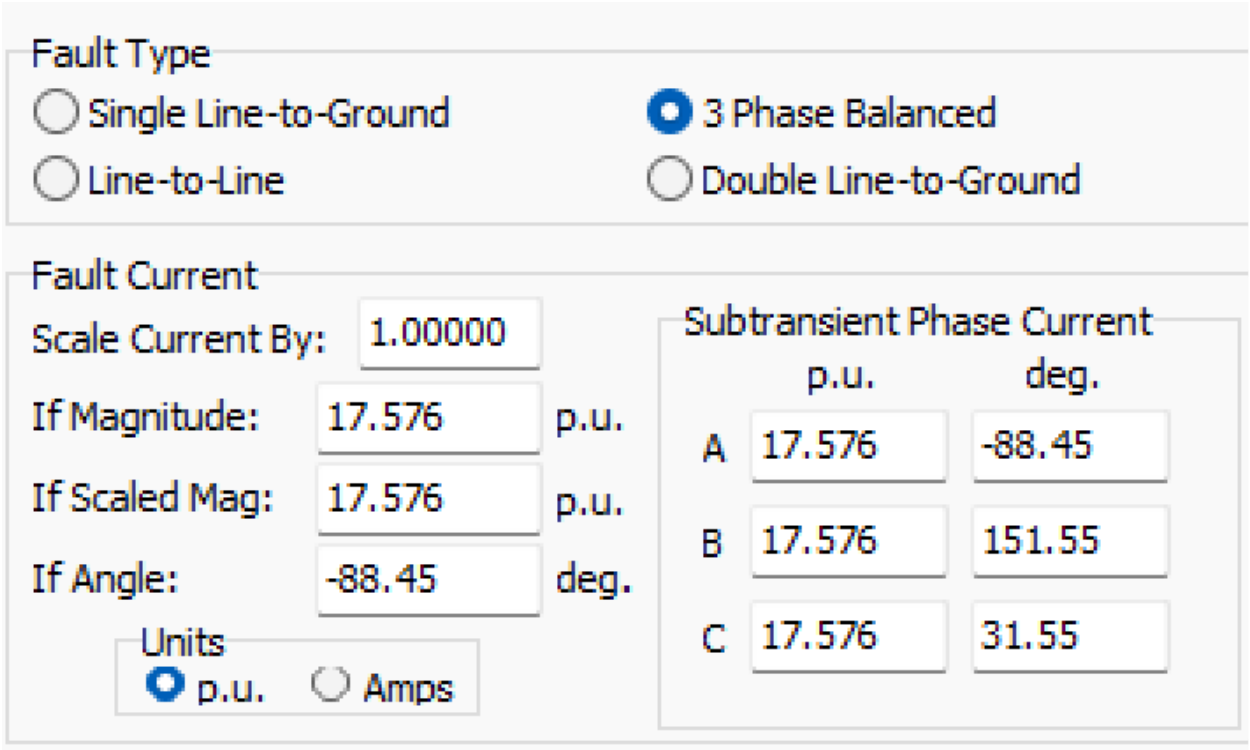


Figure 5 - PowerWorld fault current for three-phase faults at bus 3

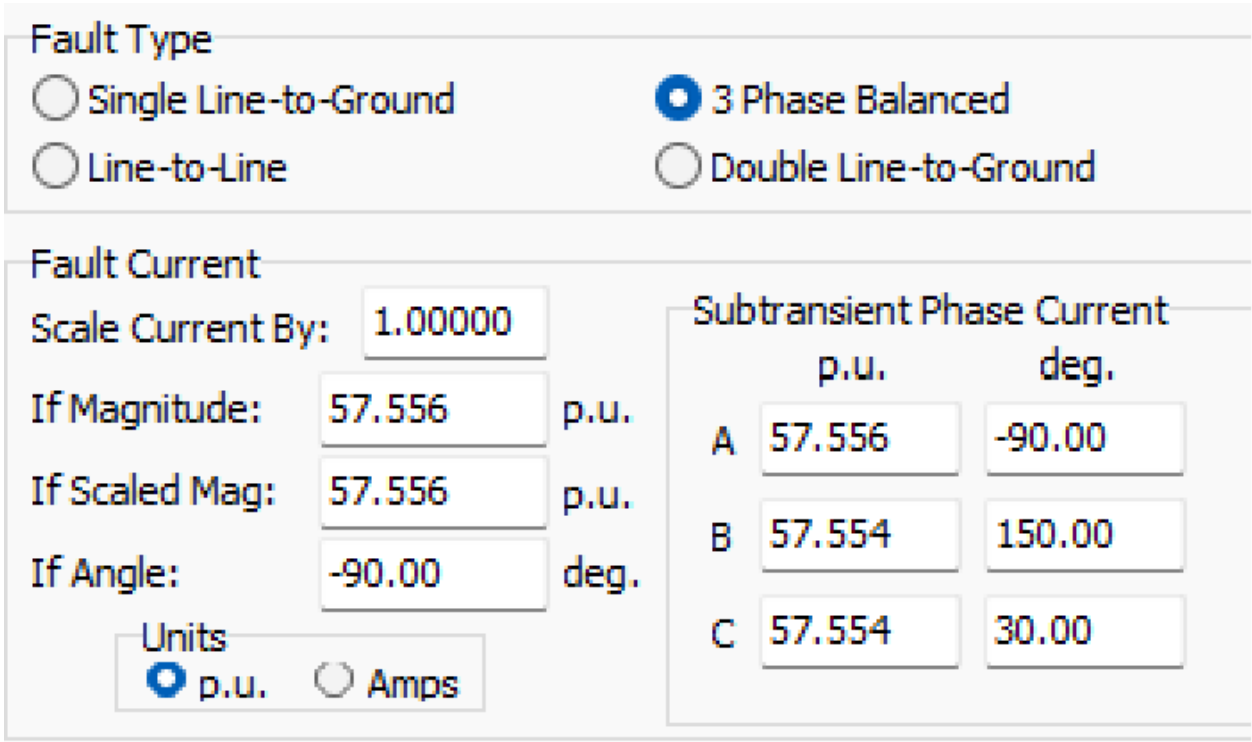


Figure 6 - PowerWorld fault current for three-phase faults at bus 4

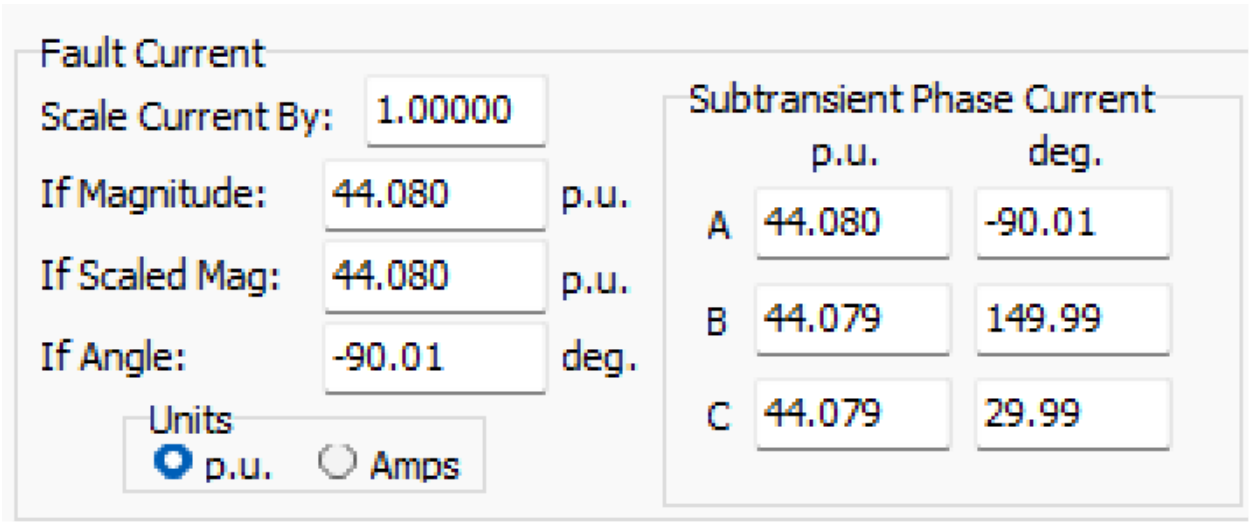
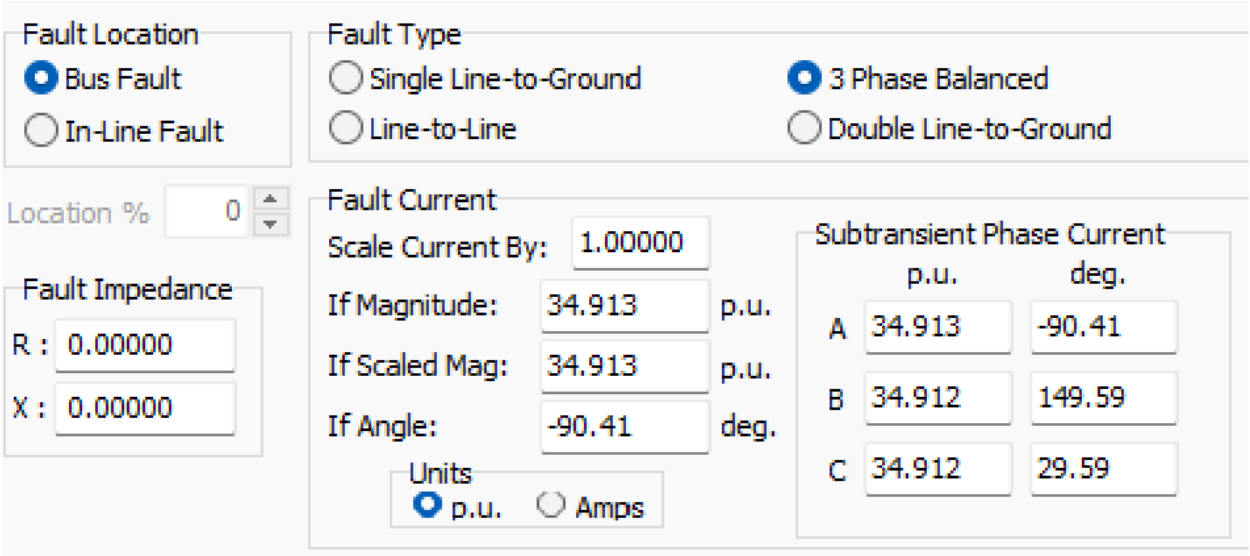
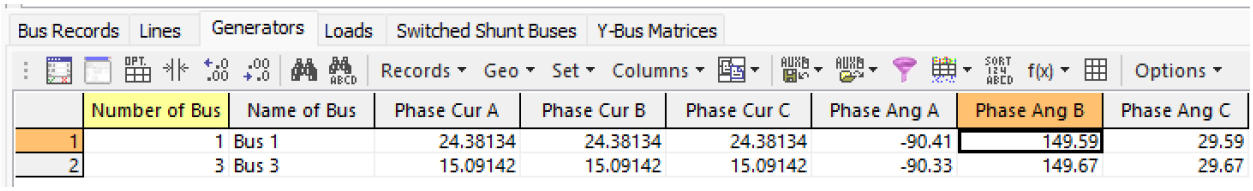


Figure 7 - PowerWorld fault current for three-phase faults at bus 5



G.D) The generators' contributions to the fault current ($IG1\ (F)$,$IG2\ (F)$) for each fault

Figure 8 - PowerWorld generators' contributions to the fault current for three-phase faults at bus 1

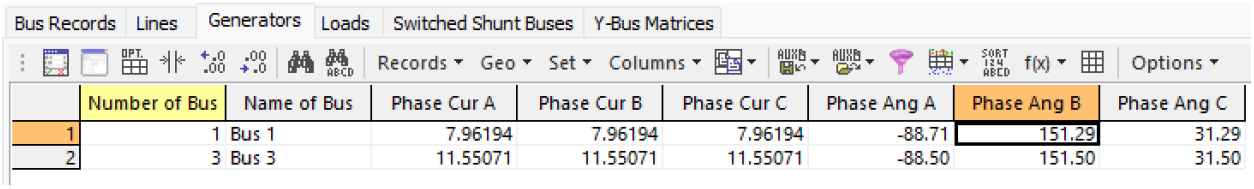


Bus Records | Lines | Generators | Loads | Switched Shunt Buses | Y-Bus Matrices

Records | Geo | Set | Columns | f(x) | Options

	Number of Bus	Name of Bus	Phase Cur A	Phase Cur B	Phase Cur C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	Bus 1	24.38134	24.38134	24.38134	-90.41	149.59	29.59
2	3	Bus 3	15.09142	15.09142	15.09142	-90.33	149.67	29.67

Figure 9 - PowerWorld generators' contributions to the fault current for three-phase faults at bus 2

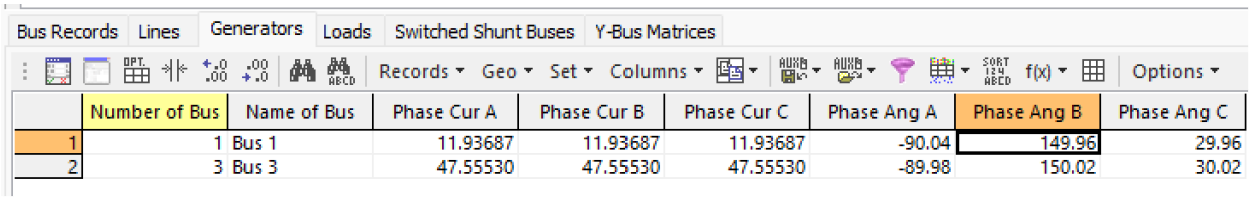


Bus Records | Lines | Generators | Loads | Switched Shunt Buses | Y-Bus Matrices

Records | Geo | Set | Columns | f(x) | Options

	Number of Bus	Name of Bus	Phase Cur A	Phase Cur B	Phase Cur C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	Bus 1	7.96194	7.96194	7.96194	-88.71	151.29	31.29
2	3	Bus 3	11.55071	11.55071	11.55071	-88.50	151.50	31.50

Figure 10 - PowerWorld generators' contributions to the fault current for three-phase faults at bus 3

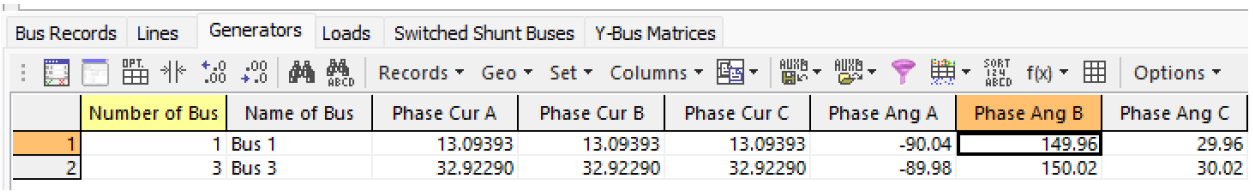


Bus Records | Lines | Generators | Loads | Switched Shunt Buses | Y-Bus Matrices

Records | Geo | Set | Columns | f(x) | Options

	Number of Bus	Name of Bus	Phase Cur A	Phase Cur B	Phase Cur C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	Bus 1	11.93687	11.93687	11.93687	-90.04	149.96	29.96
2	3	Bus 3	47.55530	47.55530	47.55530	-89.98	150.02	30.02

Figure 11 - PowerWorld generators' contributions to the fault current for three-phase faults at bus 4

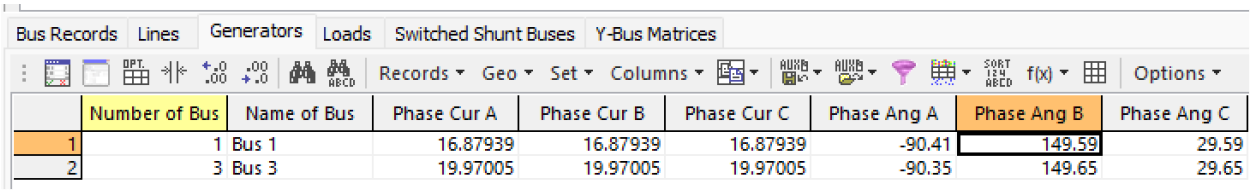


Bus Records | Lines | Generators | Loads | Switched Shunt Buses | Y-Bus Matrices

Records | Geo | Set | Columns | f(x) | Options

	Number of Bus	Name of Bus	Phase Cur A	Phase Cur B	Phase Cur C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	Bus 1	13.09393	13.09393	13.09393	-90.04	149.96	29.96
2	3	Bus 3	32.92290	32.92290	32.92290	-89.98	150.02	30.02

Figure 12 - PowerWorld generators' contributions to the fault current for three-phase faults at bus 5



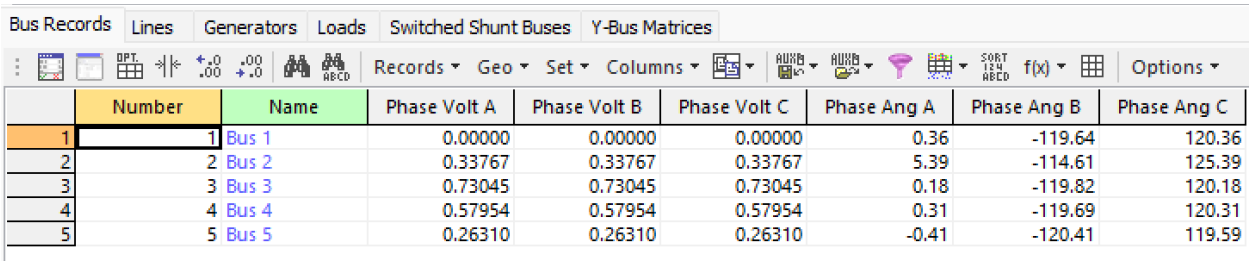
Bus Records | Lines | Generators | Loads | Switched Shunt Buses | Y-Bus Matrices

Records | Geo | Set | Columns | Options

	Number of Bus	Name of Bus	Phase Cur A	Phase Cur B	Phase Cur C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	Bus 1	16.87939	16.87939	16.87939	-90.41	149.59	29.59
2	3	Bus 3	19.97005	19.97005	19.97005	-90.35	149.65	29.65

G.E) The per-unit bus voltages during each fault ($V1$ (F),$V2$ (F),$V3$ (F),$V4$ (F), $V5$ (F))

Figure 13 - PowerWorld bus voltages during each fault for three-phase faults at bus 1

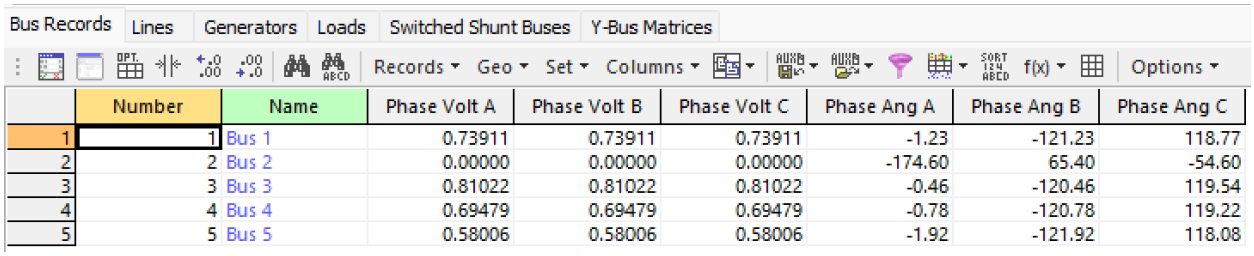


Bus Records | Lines | Generators | Loads | Switched Shunt Buses | Y-Bus Matrices

Records | Geo | Set | Columns | Options

	Number	Name	Phase Volt A	Phase Volt B	Phase Volt C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	Bus 1	0.00000	0.00000	0.00000	0.36	-119.64	120.36
2	2	Bus 2	0.33767	0.33767	0.33767	5.39	-114.61	125.39
3	3	Bus 3	0.73045	0.73045	0.73045	0.18	-119.82	120.18
4	4	Bus 4	0.57954	0.57954	0.57954	0.31	-119.69	120.31
5	5	Bus 5	0.26310	0.26310	0.26310	-0.41	-120.41	119.59

Figure 14 - PowerWorld bus voltages during each fault for three-phase faults at bus 2

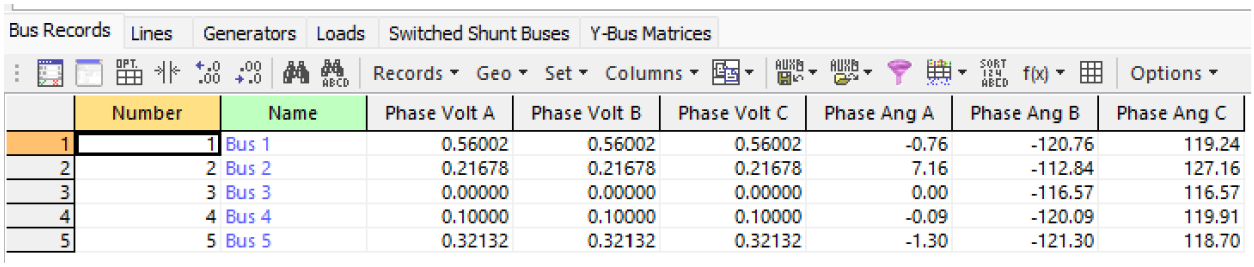


Bus Records | Lines | Generators | Loads | Switched Shunt Buses | Y-Bus Matrices

Records | Geo | Set | Columns | Options

	Number	Name	Phase Volt A	Phase Volt B	Phase Volt C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	Bus 1	0.73911	0.73911	0.73911	-1.23	-121.23	118.77
2	2	Bus 2	0.00000	0.00000	0.00000	-174.60	65.40	-54.60
3	3	Bus 3	0.81022	0.81022	0.81022	-0.46	-120.46	119.54
4	4	Bus 4	0.69479	0.69479	0.69479	-0.78	-120.78	119.22
5	5	Bus 5	0.58006	0.58006	0.58006	-1.92	-121.92	118.08

Figure 15 - PowerWorld bus voltages during each fault for three-phase faults at bus 3



Bus Records | Lines | Generators | Loads | Switched Shunt Buses | Y-Bus Matrices

Records | Geo | Set | Columns | Options

	Number	Name	Phase Volt A	Phase Volt B	Phase Volt C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	Bus 1	0.56002	0.56002	0.56002	-0.76	-120.76	119.24
2	2	Bus 2	0.21678	0.21678	0.21678	7.16	-112.84	127.16
3	3	Bus 3	0.00000	0.00000	0.00000	0.00	-116.57	116.57
4	4	Bus 4	0.10000	0.10000	0.10000	-0.09	-120.09	119.91
5	5	Bus 5	0.32132	0.32132	0.32132	-1.30	-121.30	118.70

Figure 16 - PowerWorld bus voltages during each fault for three-phase faults at bus 4

Bus Records | Lines | Generators | Loads | Switched Shunt Buses | Y-Bus Matrices

Records | Geo | Set | Columns | f(x) | Options

	Number	Name	Phase Volt A	Phase Volt B	Phase Volt C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	Bus 1	0.50796	0.50796	0.50796	-0.83	-120.83	119.17
2	2	Bus 2	0.13439	0.13439	0.13439	11.64	-108.36	131.64
3	3	Bus 3	0.32923	0.32923	0.32923	0.02	-119.98	120.02
4	4	Bus 4	0.00000	0.00000	0.00000	-0.01	-120.01	119.99
5	5	Bus 5	0.24613	0.24613	0.24613	-1.67	-121.67	118.33

Figure 17 - PowerWorld bus voltages during each fault for three-phase faults at bus 5

Bus Records | Lines | Generators | Loads | Switched Shunt Buses | Y-Bus Matrices

Records | Geo | Set | Columns | f(x) | Options

	Number	Name	Phase Volt A	Phase Volt B	Phase Volt C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	Bus 1	0.33759	0.33759	0.33759	-0.41	-120.41	119.59
2	2	Bus 2	0.11296	0.11296	0.11296	17.17	-102.83	137.17
3	3	Bus 3	0.62068	0.62068	0.62068	0.28	-119.72	120.28
4	4	Bus 4	0.42100	0.42100	0.42100	0.58	-119.42	120.58
5	5	Bus 5	0.00000	0.00000	0.00000	179.72	59.72	-60.28

Appendix:

Appendix 1 - Final Answer:

TABLE 7.6

Z_{bus} for Example 7.5

$$j\begin{bmatrix} 0.0279725 & 0.0177025 & 0.0085125 & 0.0122975 & 0.020405 \\ 0.0177025 & 0.0569525 & 0.0136475 & 0.019715 & 0.02557 \\ 0.0085125 & 0.0136475 & 0.0182425 & 0.016353 & 0.012298 \\ 0.0122975 & 0.019715 & 0.016353 & 0.0236 & 0.017763 \\ 0.020405 & 0.02557 & 0.012298 & 0.017763 & 0.029475 \end{bmatrix}$$

TABLE 7.7

Fault currents and bus voltages for Example 7.5

Fault Bus	Fault Current (per unit)	Contributions to Fault Current: Gen Line or TRSF	Bus-to-Bus	Current (per unit)
1	37.536			
		G 1	GRND–1	23.332
		T 1	5–1	14.204
2	18.436			
		L 1	4–2	6.864
		L 2	5–2	11.572
3	57.556			
		G 2	GRND–3	46.668
		T 2	4–3	10.888
4	44.456			
		L 1	2–4	1.736
		L 3	5–4	10.412
		T 2	3–4	32.308
5	35.624			
		L 2	2–5	2.78
		L 3	4–5	16.688
		T 1	1–5	16.152

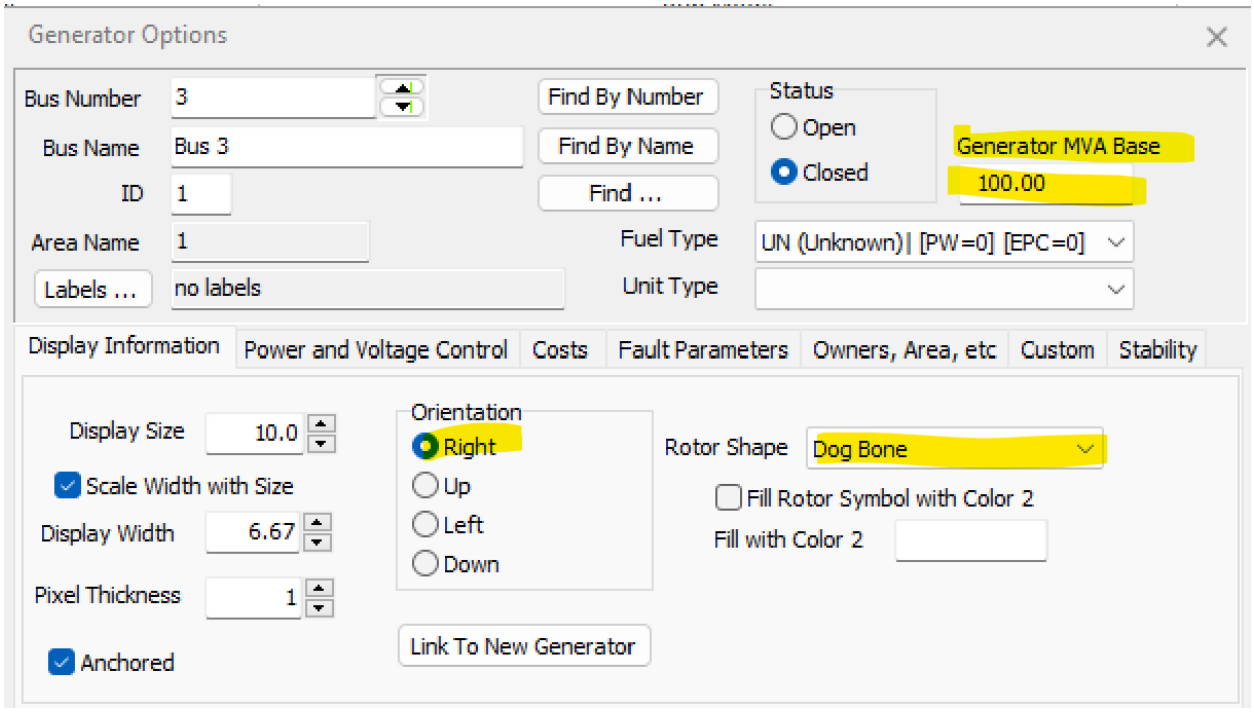
$V_F = 1.05$ Fault Bus:	Per-Unit Bus Voltage Magnitudes during the Fault: Bus 1	Bus 2	Bus 3	Bus 4	Bus 5
1	0.0000	0.7236	0.5600	0.5033	0.3231
2	0.3855	0.0000	0.2644	0.1736	0.1391
3	0.7304	0.7984	0.0000	0.3231	0.6119
4	0.5884	0.6865	0.1089	0.0000	0.4172
5	0.2840	0.5786	0.3422	0.2603	0.0000

Link for Reference on how to use PowerWorld Simulation:
https://www.youtube.com/watch?v=g46LVp-jWPQ

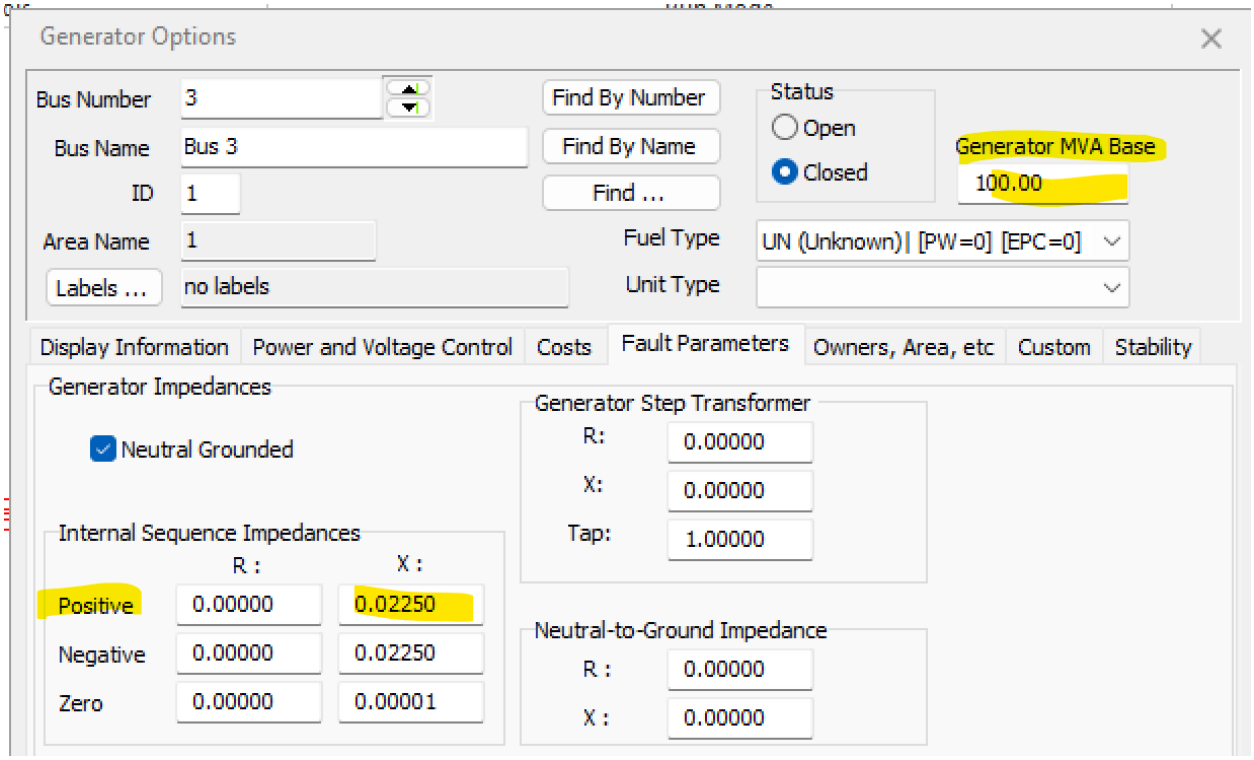
https://www.youtube.com/watch?v=2Gy6vT9fDk0

Generator #2 Parameters:

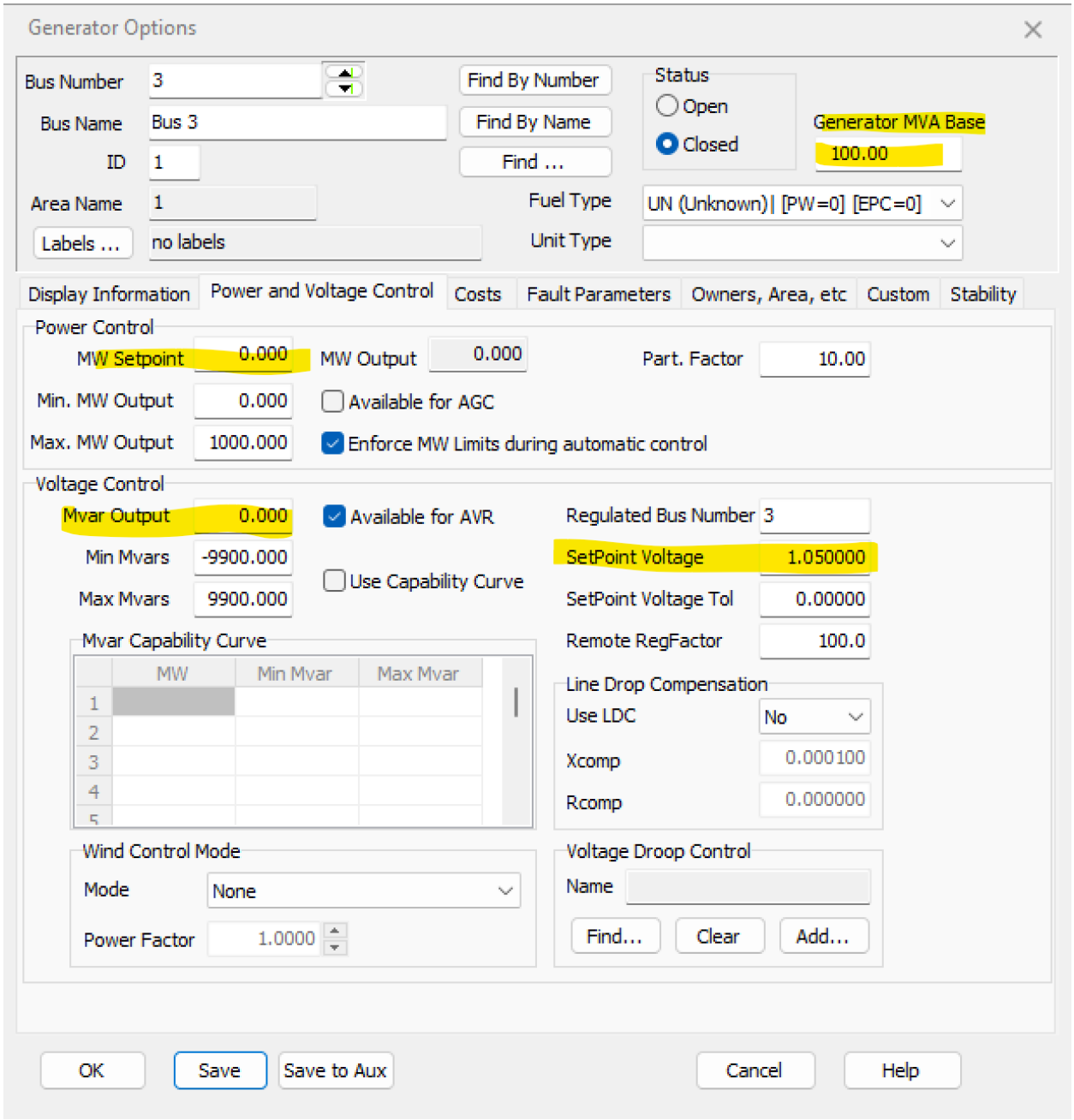
Appendix 2 - Generator 2 Display Info Set Parameters (Rigth Generator)



Appendix 3 - Generator 2 Fault Parameters Set Parameters (Rigth Generator)

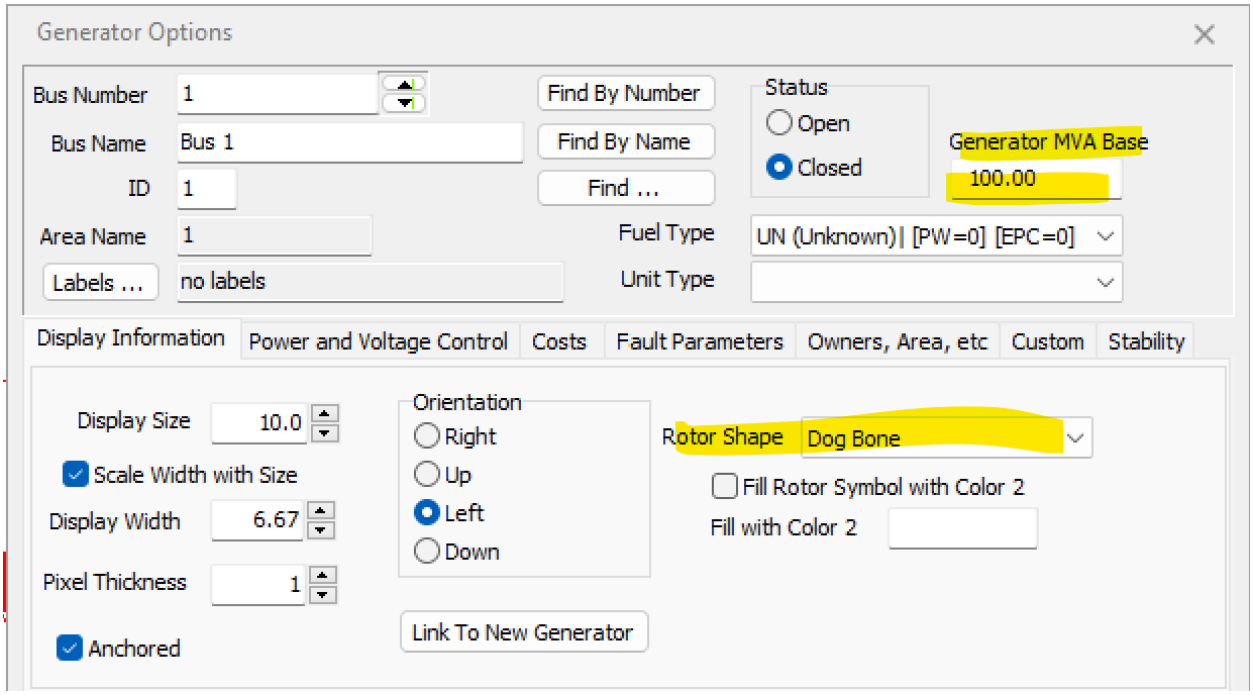


Appendix 4 - Generator 2 Power and Voltage Controls Set Parameters (Rigth Generator)

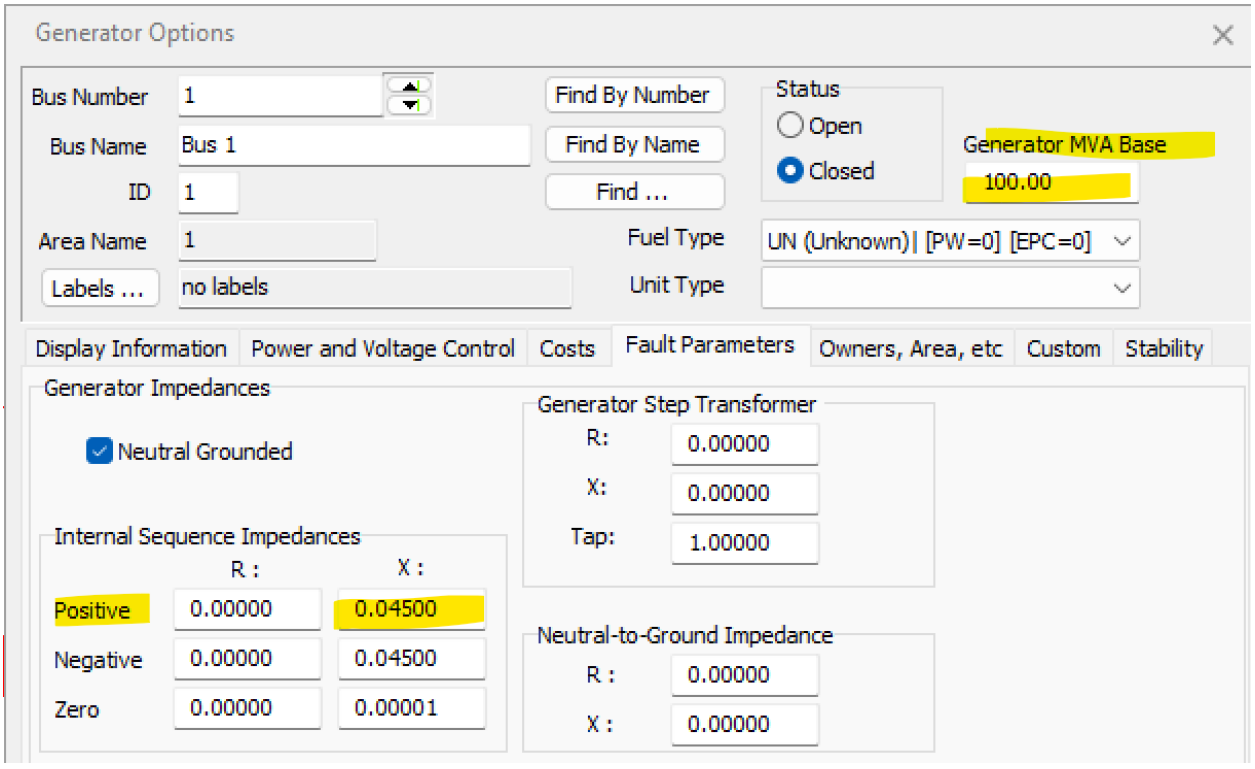


Generator #1 Parameters:

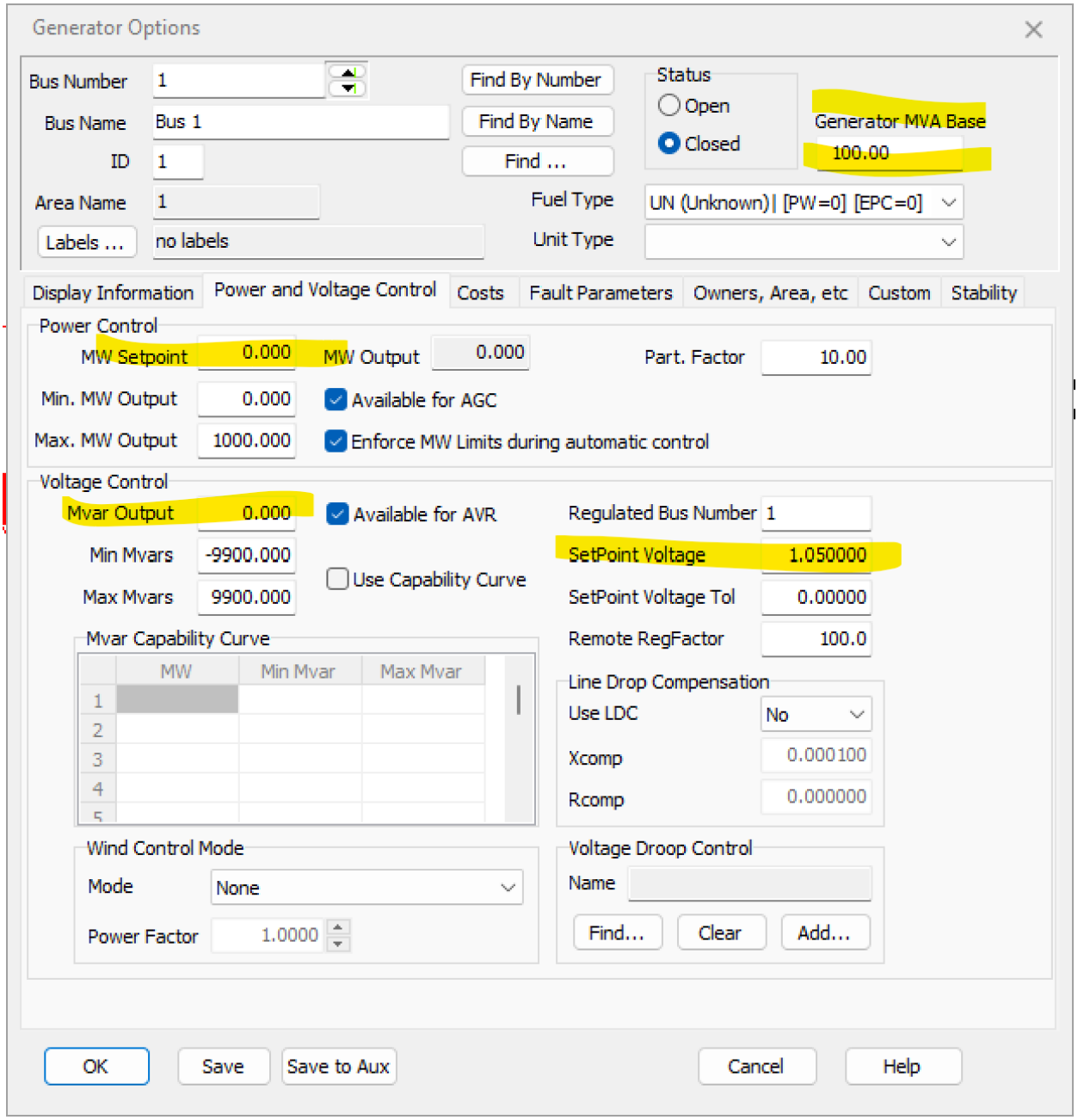
Appendix 5 -Generator 1 Display Info Set Parameters (Left Generator)



Appendix 6 -Generator 1 Fault Parameters Set Parameters (Left Generator)

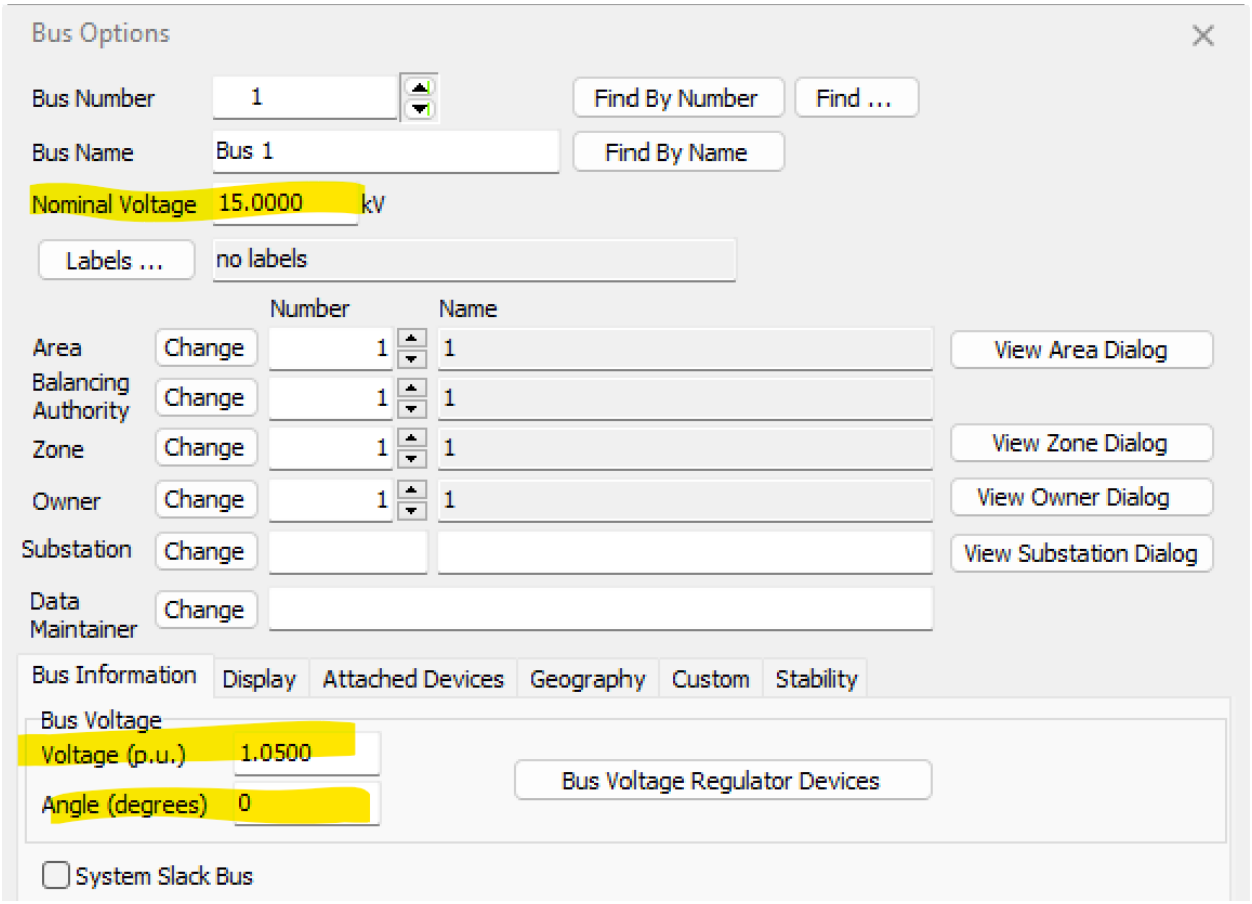


Appendix 7 -Generator 1 Power and Voltage Control Set Parameters (Left Generator)

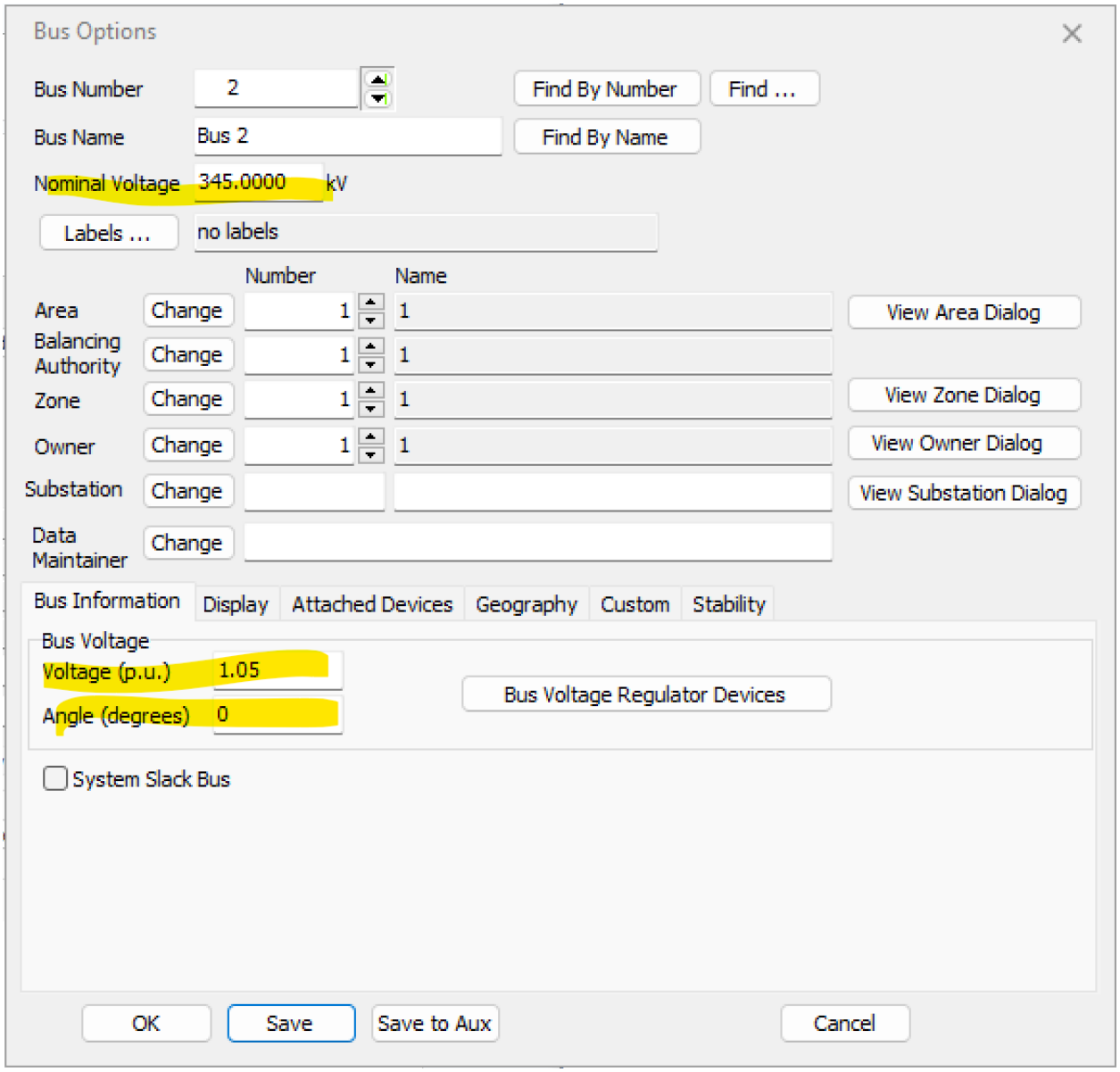


Bus Parameters:

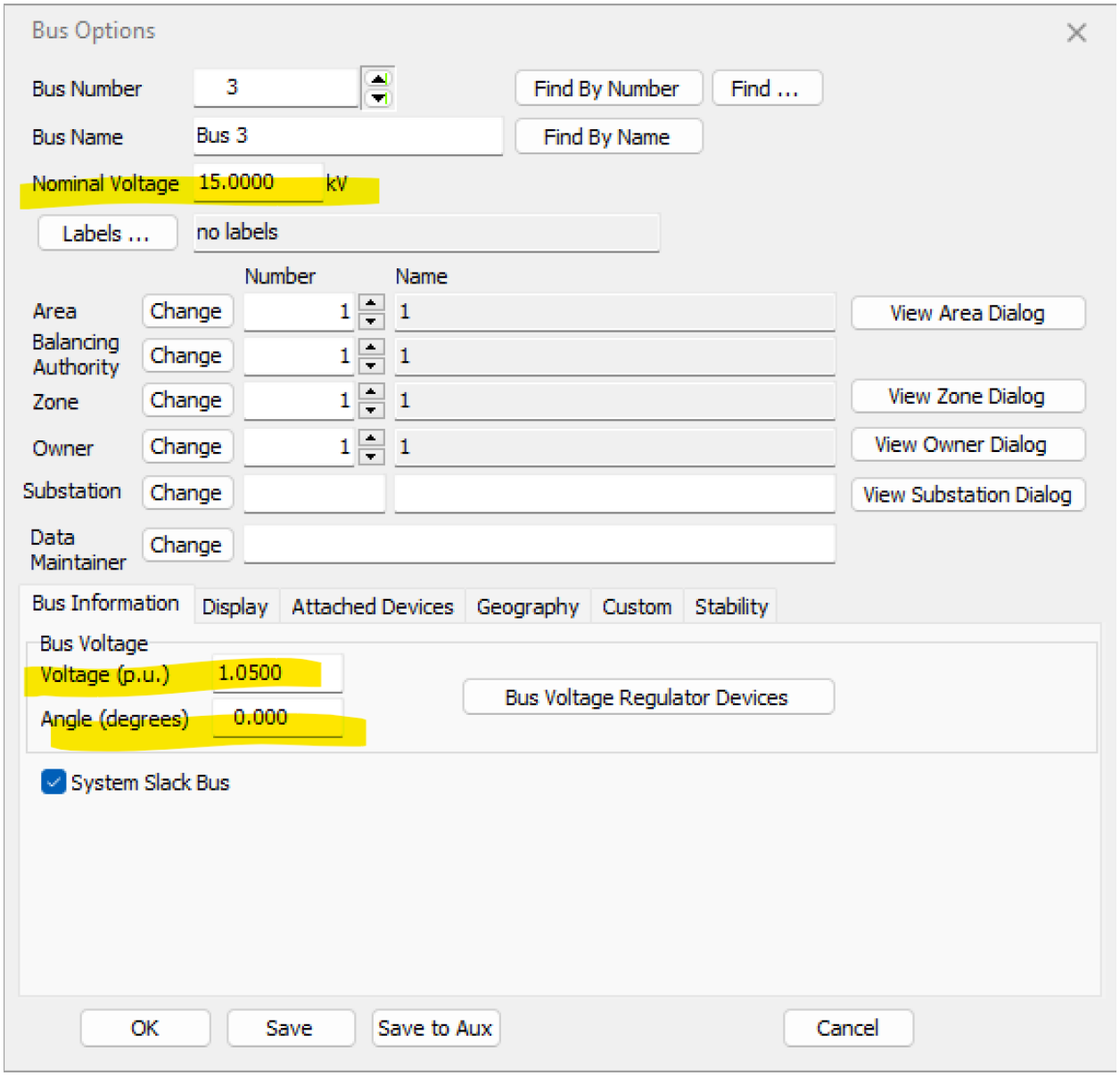
Appendix 8 - Bus 1 Parameter



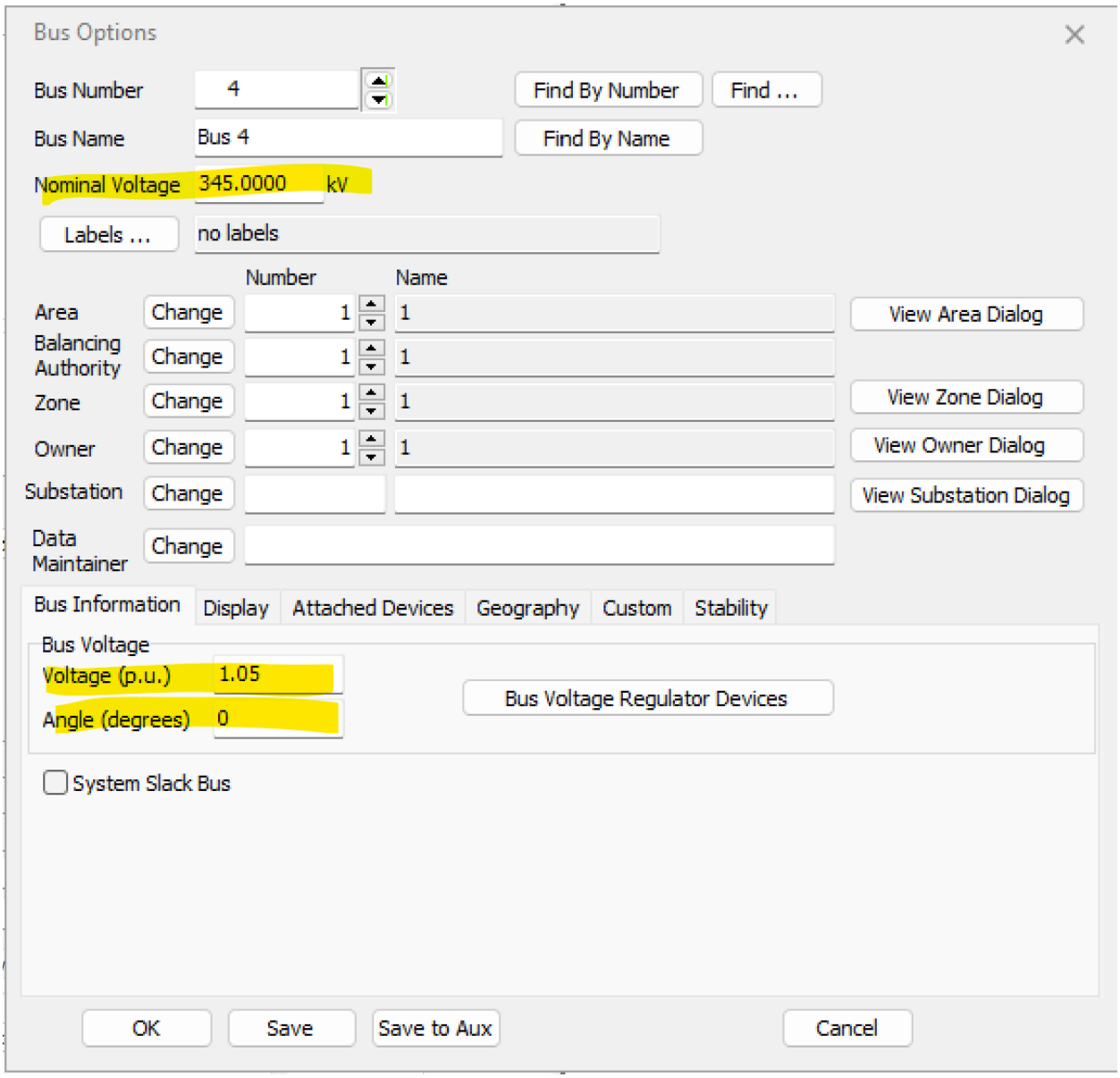
Appendix 9 - Bus 2 Parameter



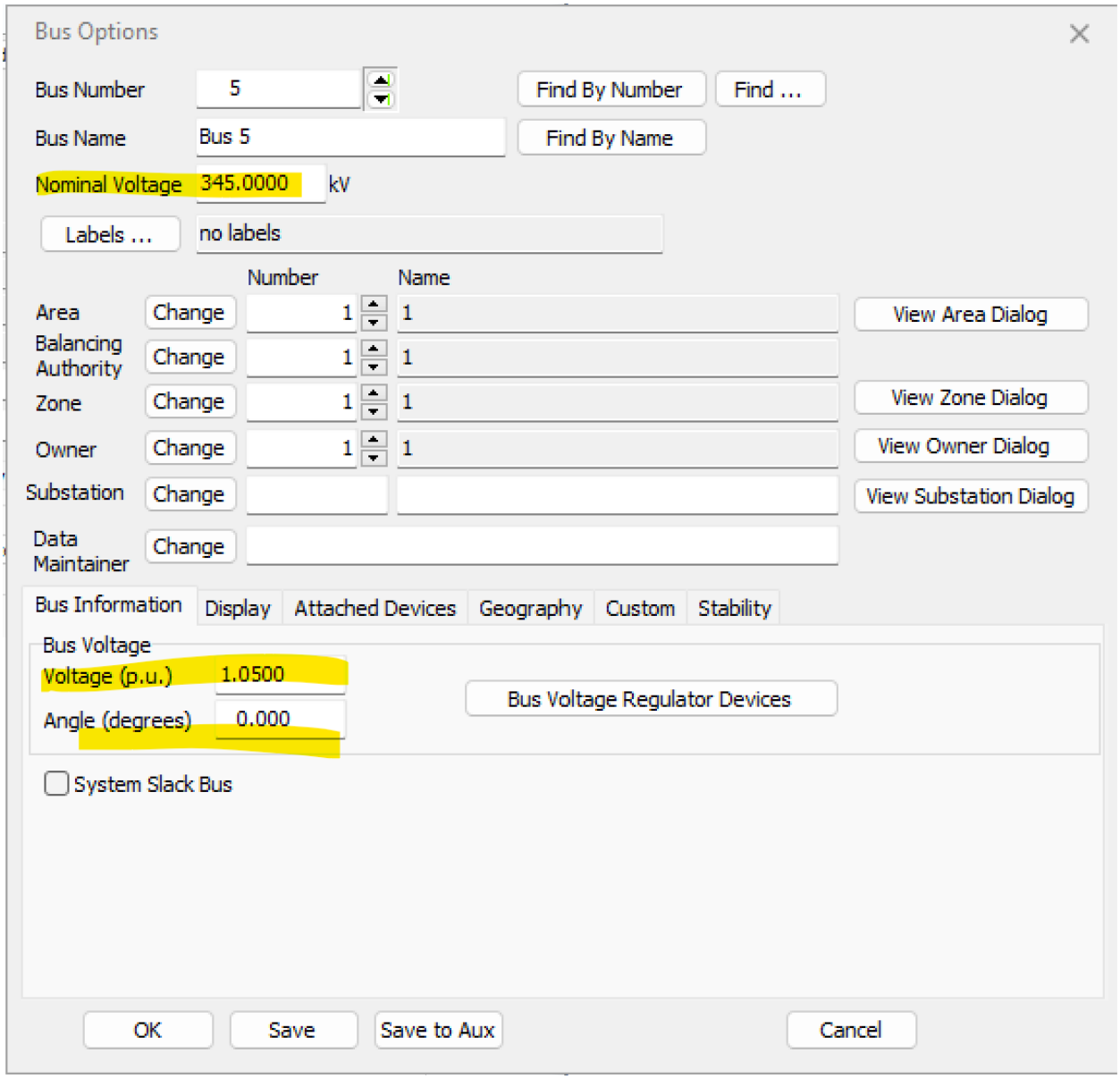
Appendix 10 - Bus 3 Parameter



Appendix 11 - Bus 4 Parameter

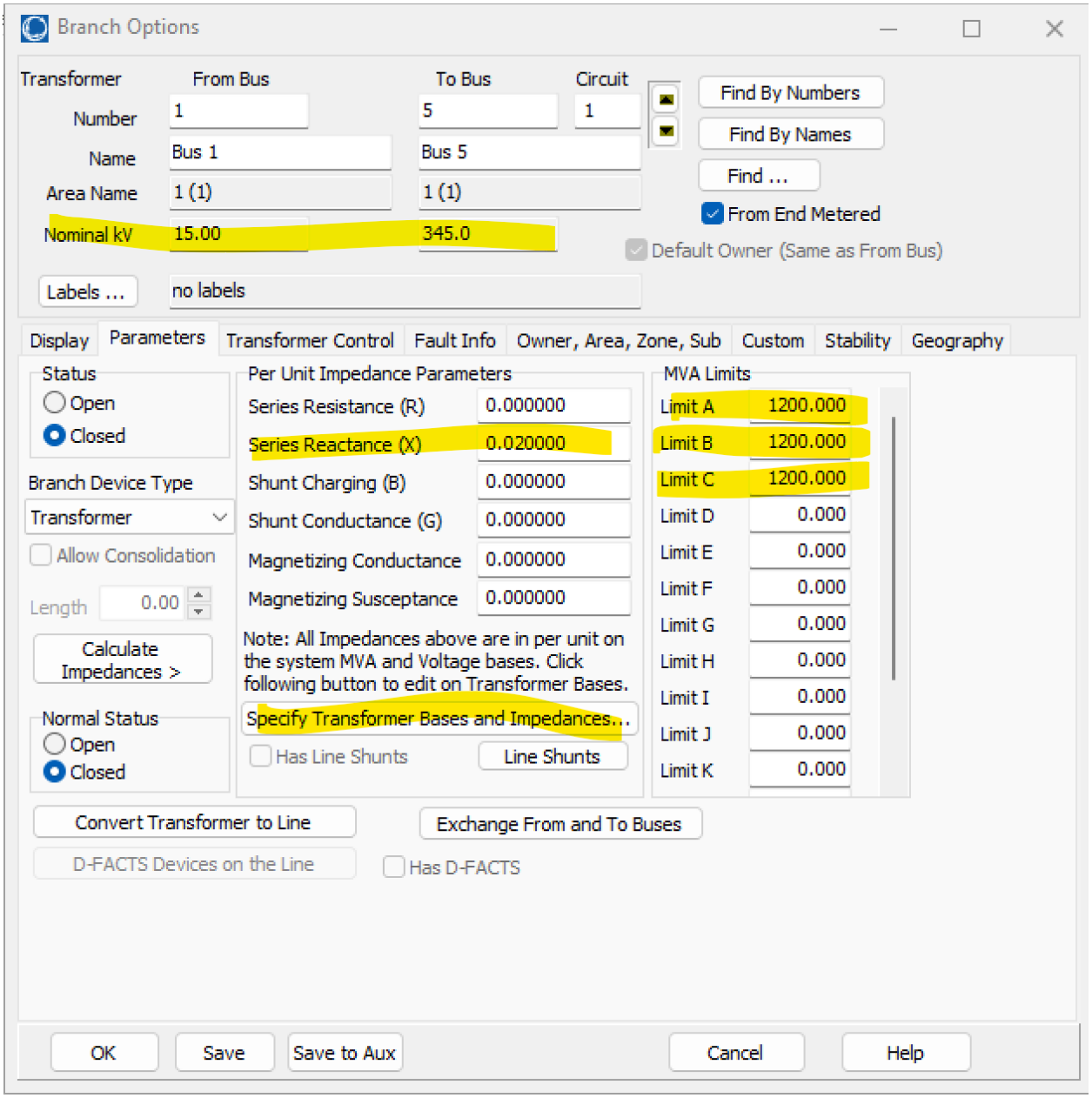


Appendix 12 - Bus 5 Parameter

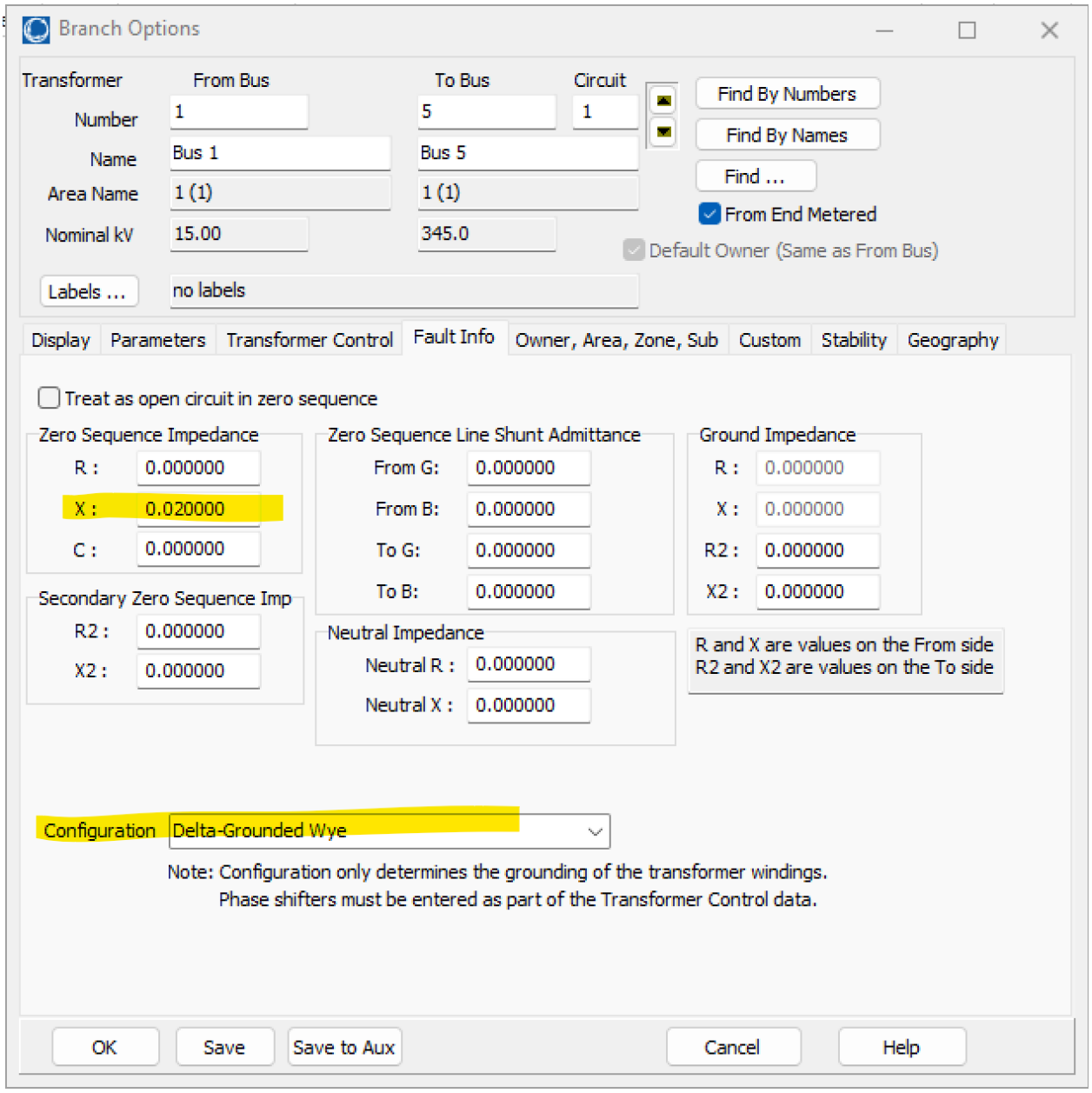


Transformer #1 Parameters:

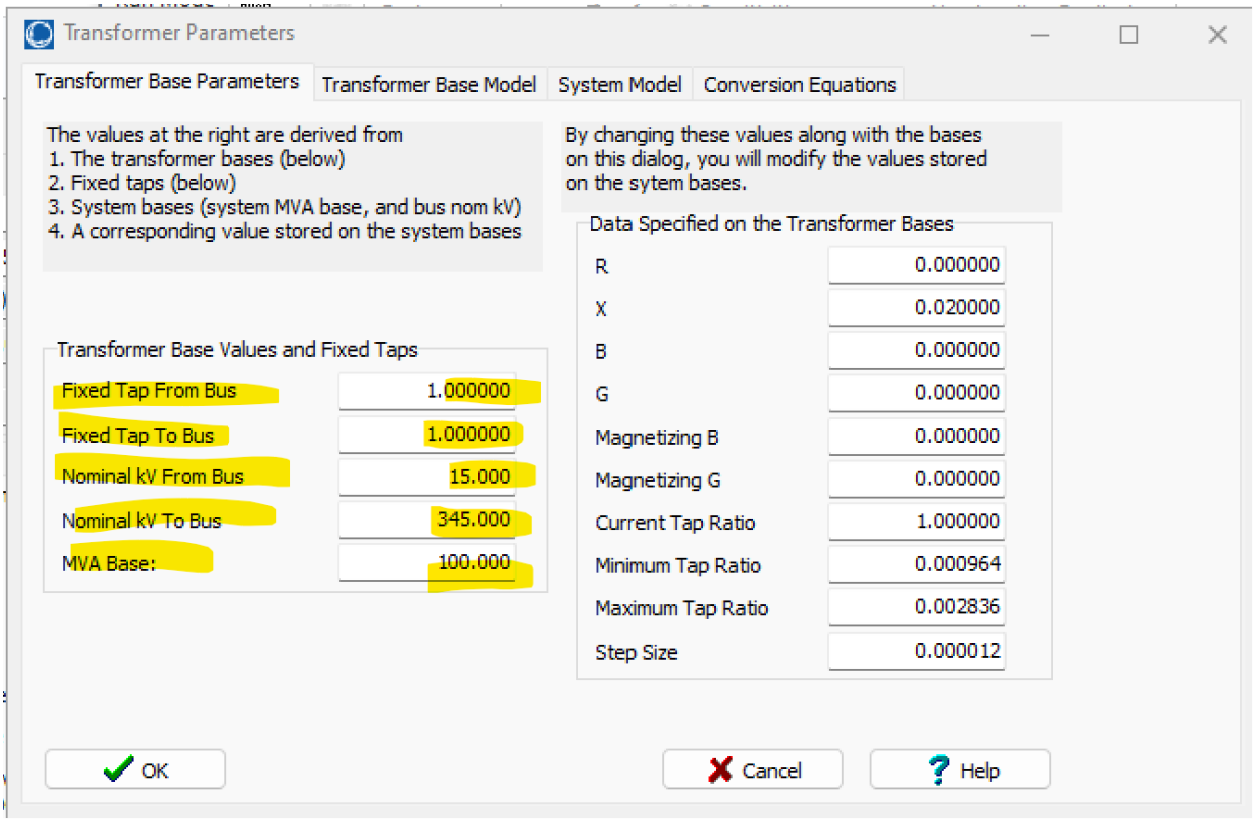
Appendix 13 - Transmission #1 Parameters set Parameters



Appendix 14 - Transmission #1 Fault info Set Parameters

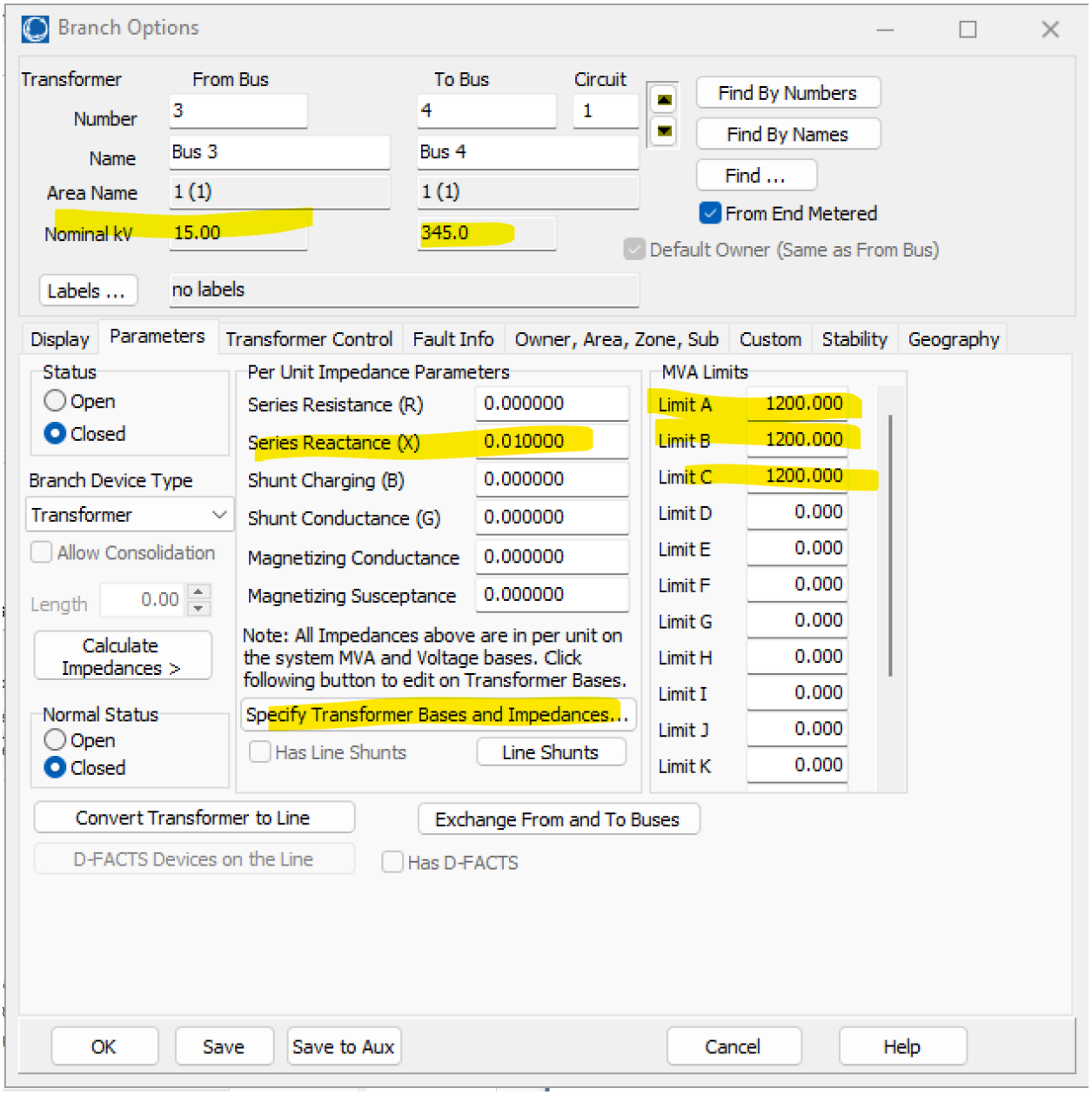


Appendix 15 - Transmission #1 Specify Transformer Based and Impedances

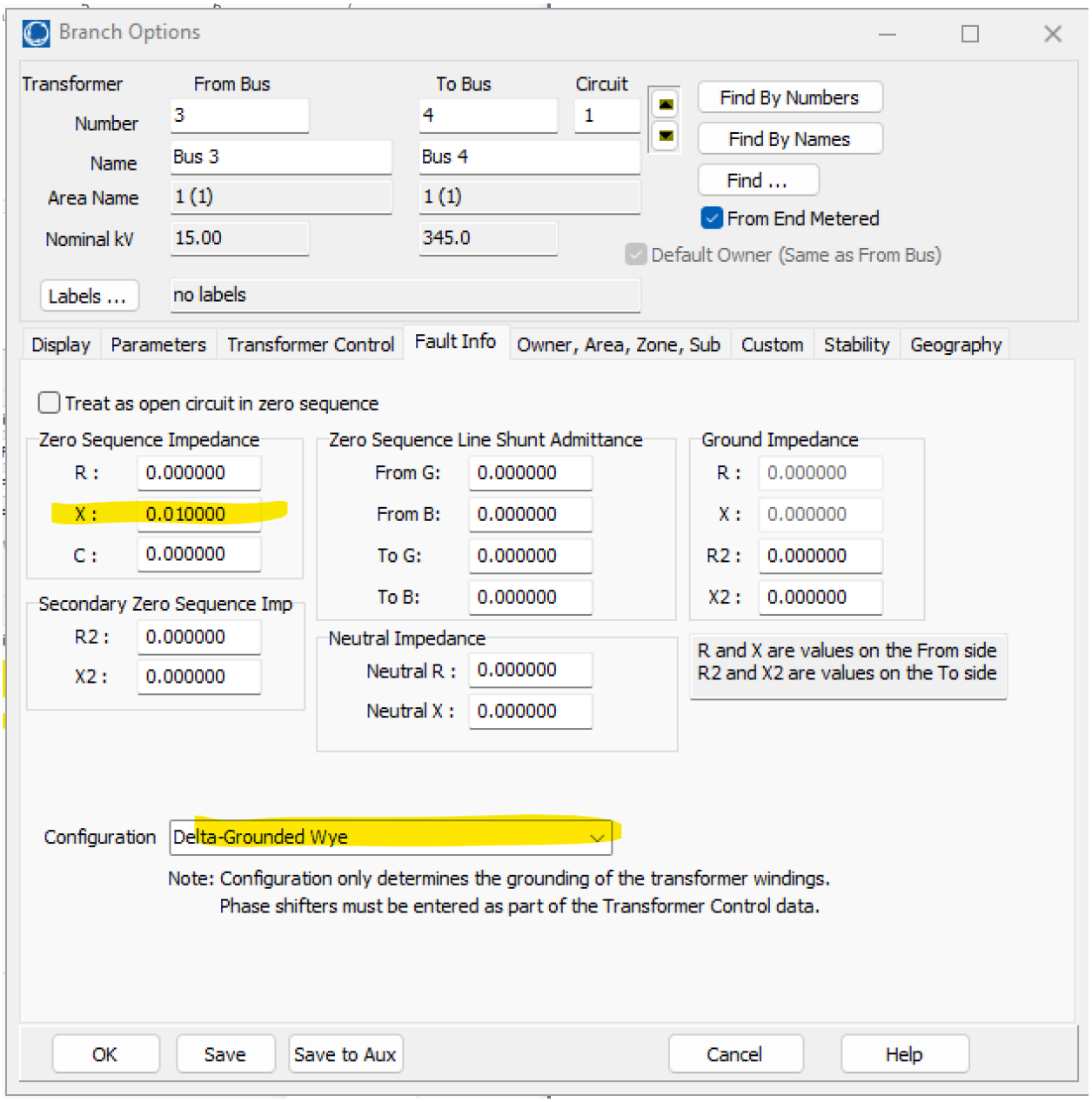


Transformer #2 Parameters:

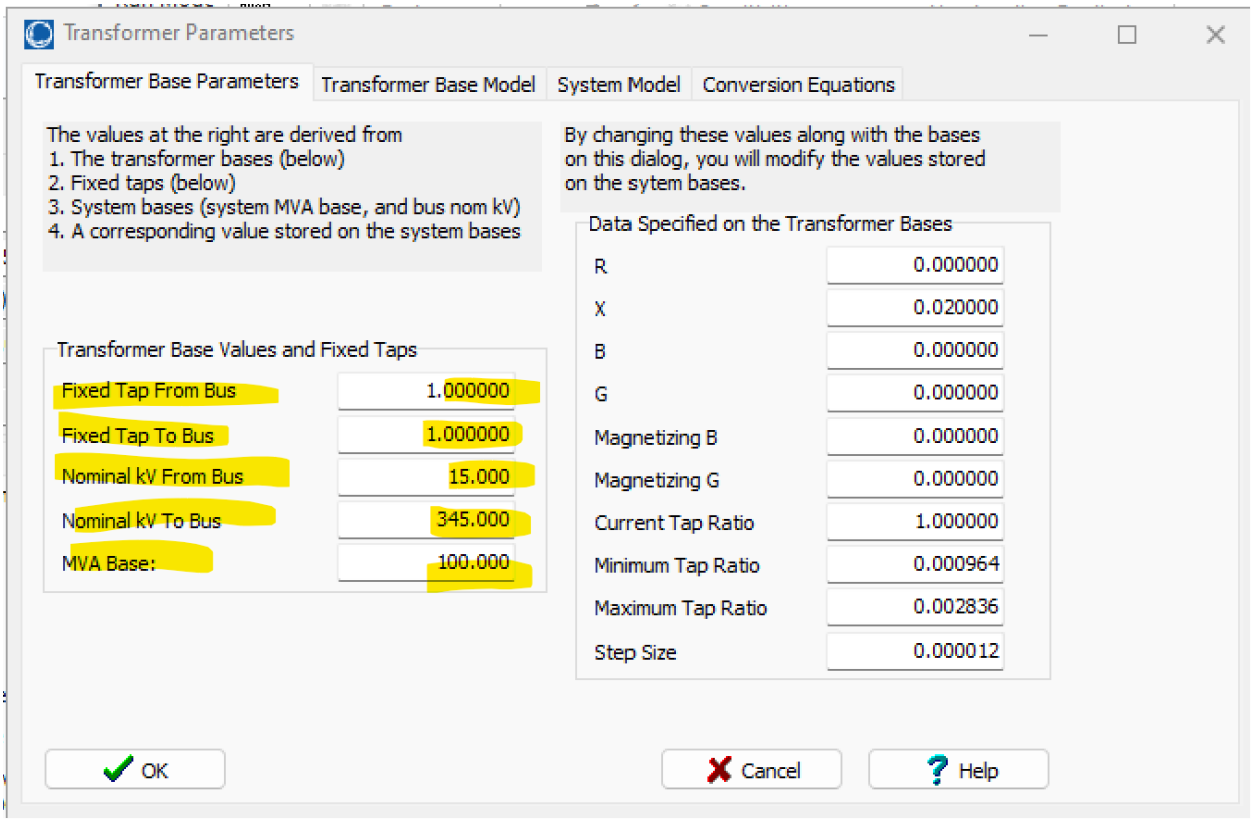
Appendix 16 - Transmission #2 Parameters set Parameters



Appendix 17 - Transmission #2 Fault info Set Parameters

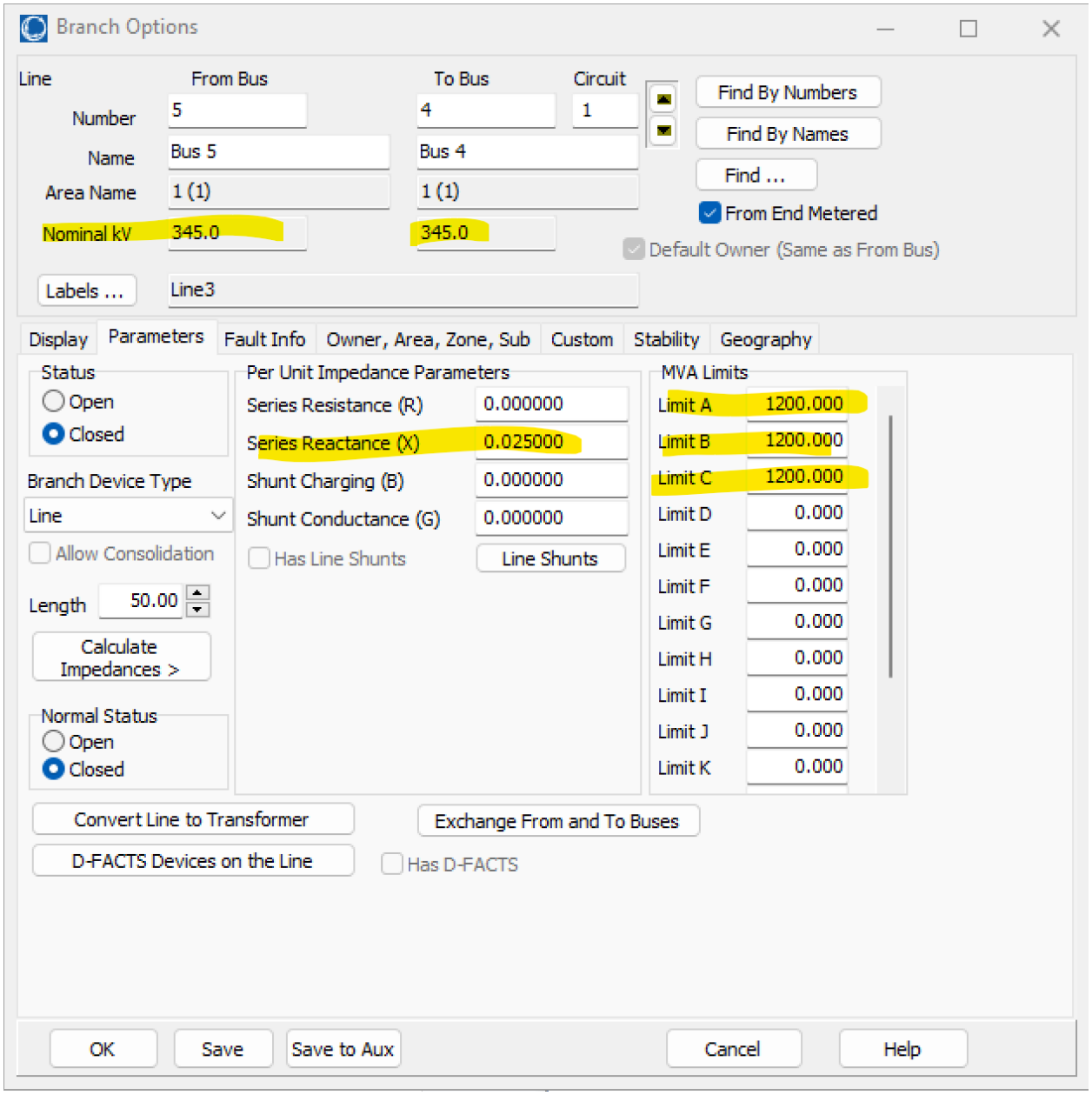


Appendix 18 - Transmission #2 Specify Transformer Based and Impedances



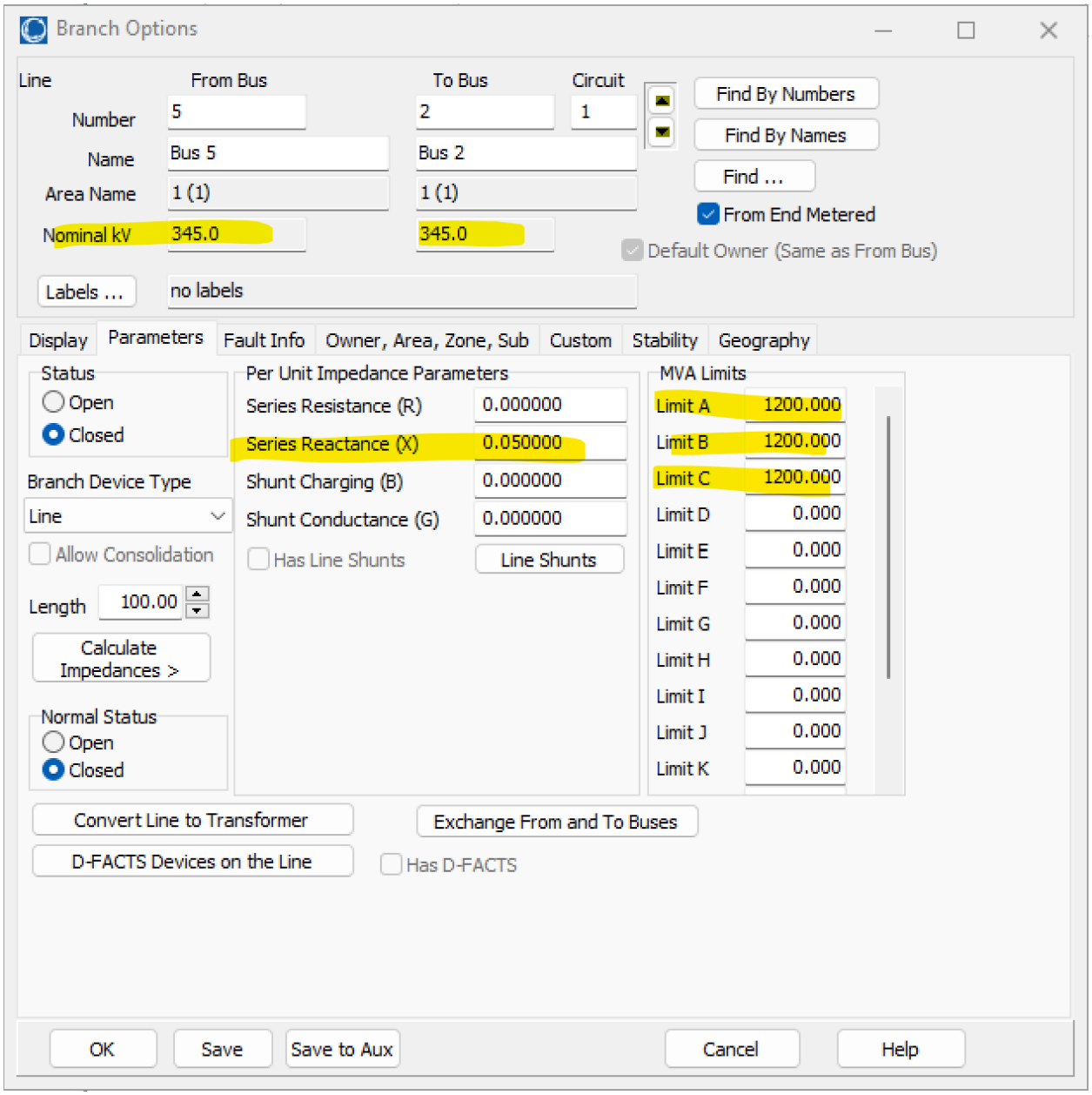
Line #3 Parameters:

Appendix 19 - Line 3 Set Parameters



Line #2 Parameters:

Appendix 20 - Line 2 Set Parameters



Line #1 Parameters:

Appendix 21 - Line 1 Set Parameters